



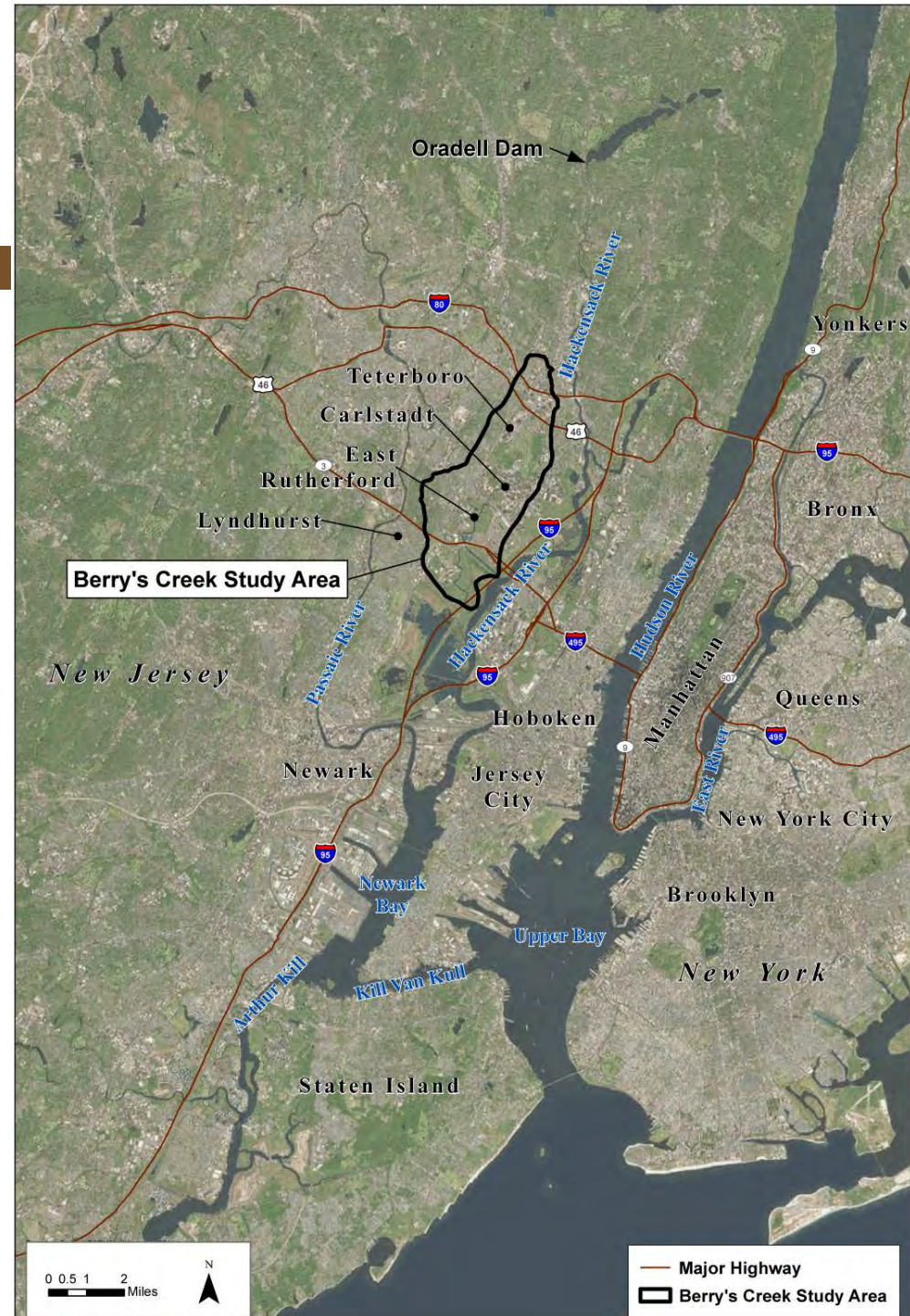
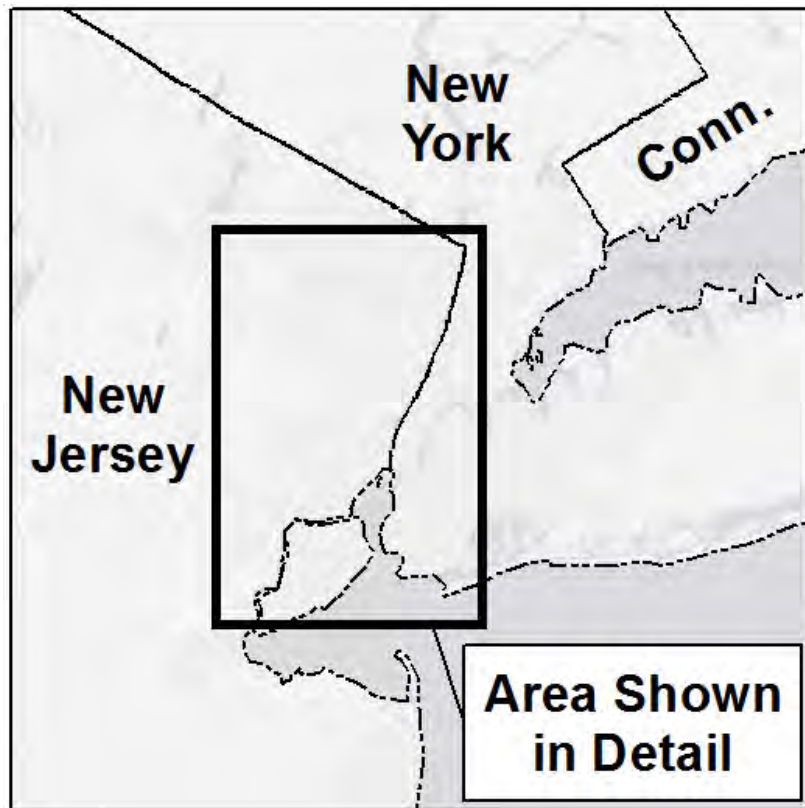
REMEDIAL INVESTIGATION KEY FINDINGS

April 13, 2016

Berry's Creek Study Area

Berry's Creek Study Area

2

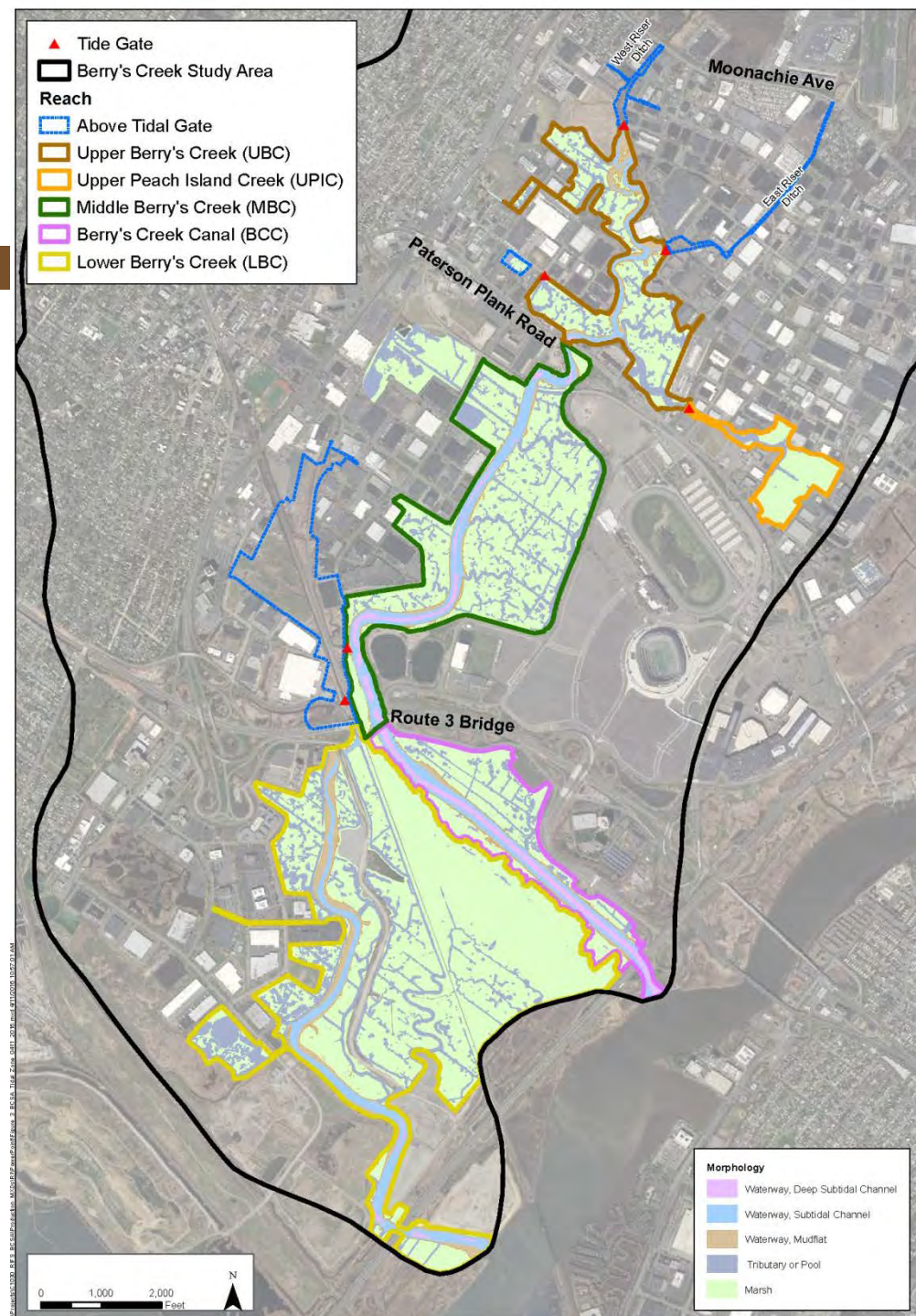


BCSA

Landscape

3

- BCSA Watershed
- Tidal Area
 - ▣ Upper Berry's Creek
 - ▣ Middle Berry's Creek
 - ▣ Berry's Creek Canal
 - ▣ Lower Berry's Creek
- Areas above tide gate

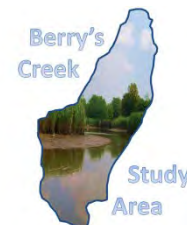


RI Approach

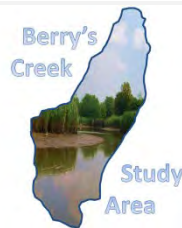
4

- **Site-specific study questions**
 - ▣ **Framed in Work Plan**
 - ▣ **Answered to define risk, evaluate remedy (need/nature)**

- **Conceptual site models (CSMs)**
 - ▣ **Physical, chemical, biological linkages**
 - ▣ **Framed in Work Plan, updated throughout RI**
 - ▣ **Used to answer Study Questions**



5 Summary of Characterization Efforts

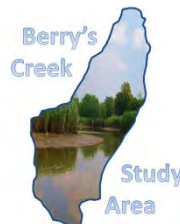


Scoping Activities (2007 – 2008)

6

Nine pre-RI activities to advance the understanding of the BCSA, support development of preliminary CSMs, and refine study questions

- Physical template
- Aerial photograph analyses
- Study area reconnaissance
- Water Budget
- Data compilation and analysis
- Reference area identification
- Ecologically relevant receptors identification
- Conceptual site models
- Methods development

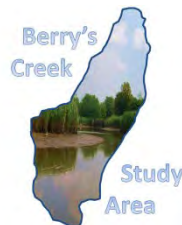


Phase 1 (2009 – 2010)

7

Primary focus – characterization of horizontal and vertical distribution of COPCs

- Initial characterization of the aquatic community
- System hydrodynamics and sediment transport dynamics
- Screening of reference sites

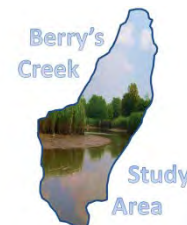


Phase 2 (2010 – 2011)

8

Detailed site characterization building on Phase 1 findings

- COPC concentrations in marsh sediment and biota tissue
- Horizontal and vertical COPC distribution in waterways
- Factors influencing COPC fate and transport
- Hydrodynamic and sediment transport monitoring
- Monitoring during Hurricane Irene
- Assessment of the aquatic and marsh communities, the aquatic food web, and marsh functions and values

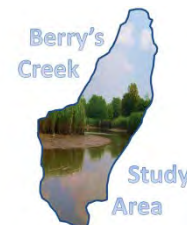


Phase 3 (2012 – 2015)

9

Focus on understanding COPC transport and fate, and factors controlling COPC bioavailability and biouptake

- Porewater and voltammetry
- Upland flow and sediment loading
- Optical monitoring
- Bathymetric analysis
- High resolution sediment cores
- Soft sediment probing
- COPC concentrations in recently deposited sediment
- Sequential extraction analyses
- Characterization of the aquatic community and food web
- COPCs in a range of aquatic species
- Toxicity testing
- Dioxin/furan characterization
- Marsh vegetation community surveys

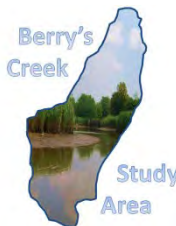


Baseline Monitoring (2011 – Ongoing)

10

Data to assess temporal trends within the BCSA in response to remedial actions or other changes in the system

- Mummichog and white perch at 40 locations in BCSA and 20 stations in the Bellman's Creek and Mill Creek reference sites
- Surface water: automated monitoring at 4 locations in the BCSA, and manual water sampling in proximity to the BCSA biota sampling locations

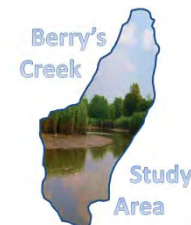


Summary of RI Samples (2008 – 2015)

11

Study Area	Media				Total Samples
	Sediment		Water	Tissue	
	Waterway	Marsh			
Above Tide Gates	254	56	441	23	774
UBC	1005	442	1182	348	2977
MBC	1075	332	1008	360	2775
BCC	373	67	487	241	1168
LBC	403	224	359	291	1277
BCSA Subtotal	3110	1121	3477	1263	8971
Reference Areas	65	131	368	754	1318
Total	3175	1252	3845	2017	10,289

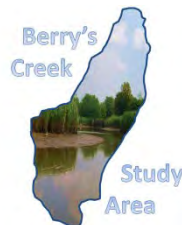
Notes: Total sample count does not include samples collected by UOP or Morton, or TS-PS samples.



Summary of Key Findings

12

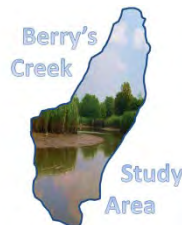
1. **The BCSA includes a stable and net depositional tidal area**
2. **COPC concentrations are substantially higher in the northern end of the study area**
3. **The urban setting has altered the physical, chemical, and biological character of the BCSA, which is distinctly different from non-urban areas**
4. **Most COPC concentrations are lower at the sediment surface and are substantially higher at depth**



Summary of Key Findings

13

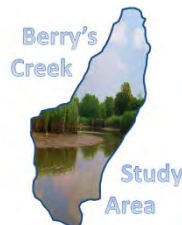
5. **Natural recovery is occurring in the waterways, though variable in magnitude due to occasional episodic re-working and resuspension of near surface sediment in localized areas**
6. **Marsh natural recovery is substantial and consistent, and is linked to sediment and COPC inputs from waterways**
7. **Natural conditions in the fringing marsh system sequester COPCs and reduce bioavailability**



Summary of Key Findings

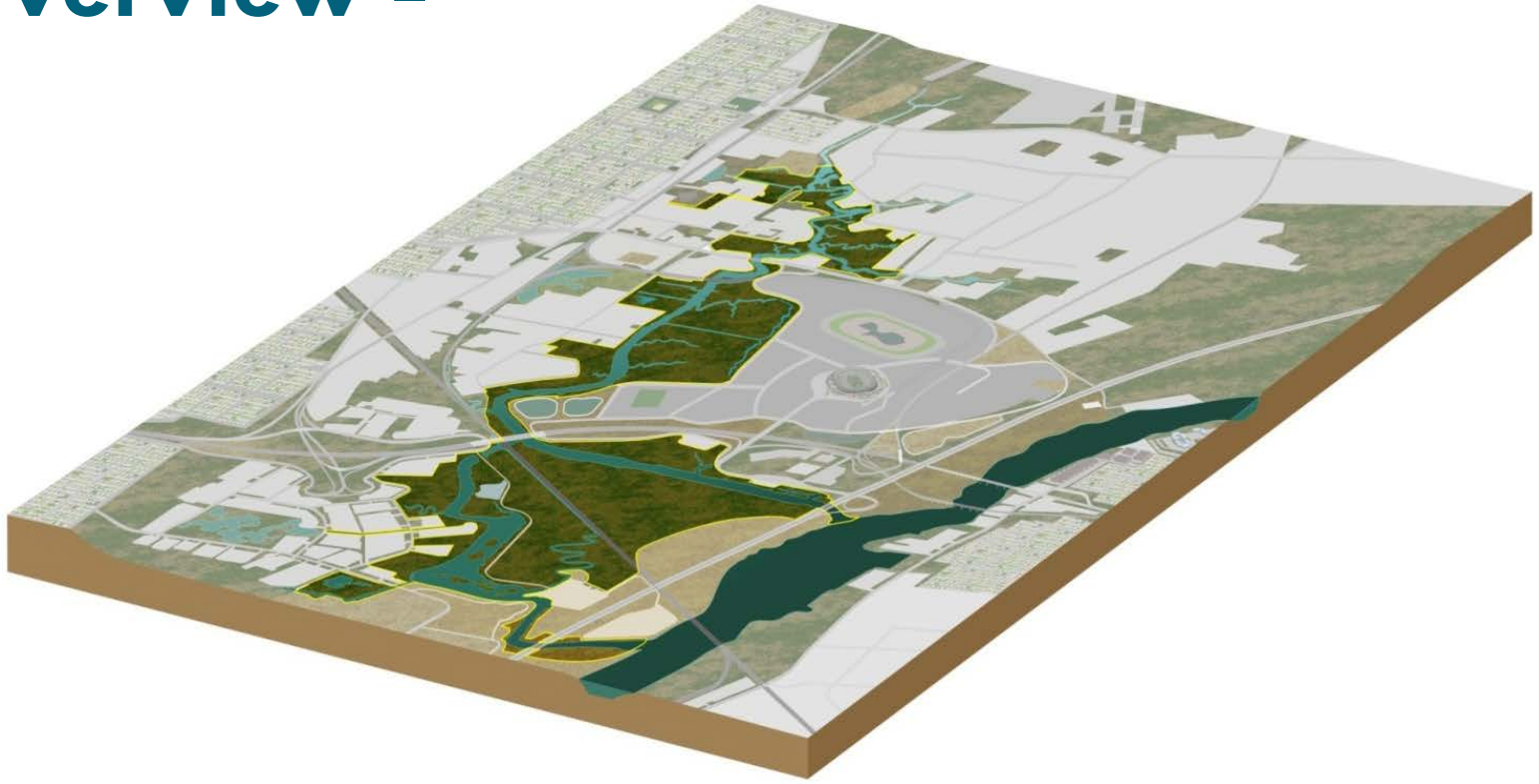
14

- 8. **COPC biouptake is linked surface sediment in the waterways and tributaries**
- 9. **BCC and LBC COPC concentrations are attenuating consistent with regional conditions**



CSM Overview - Setting

15

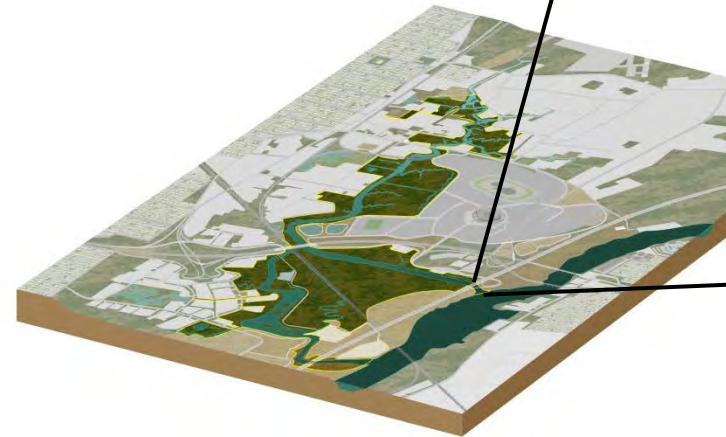
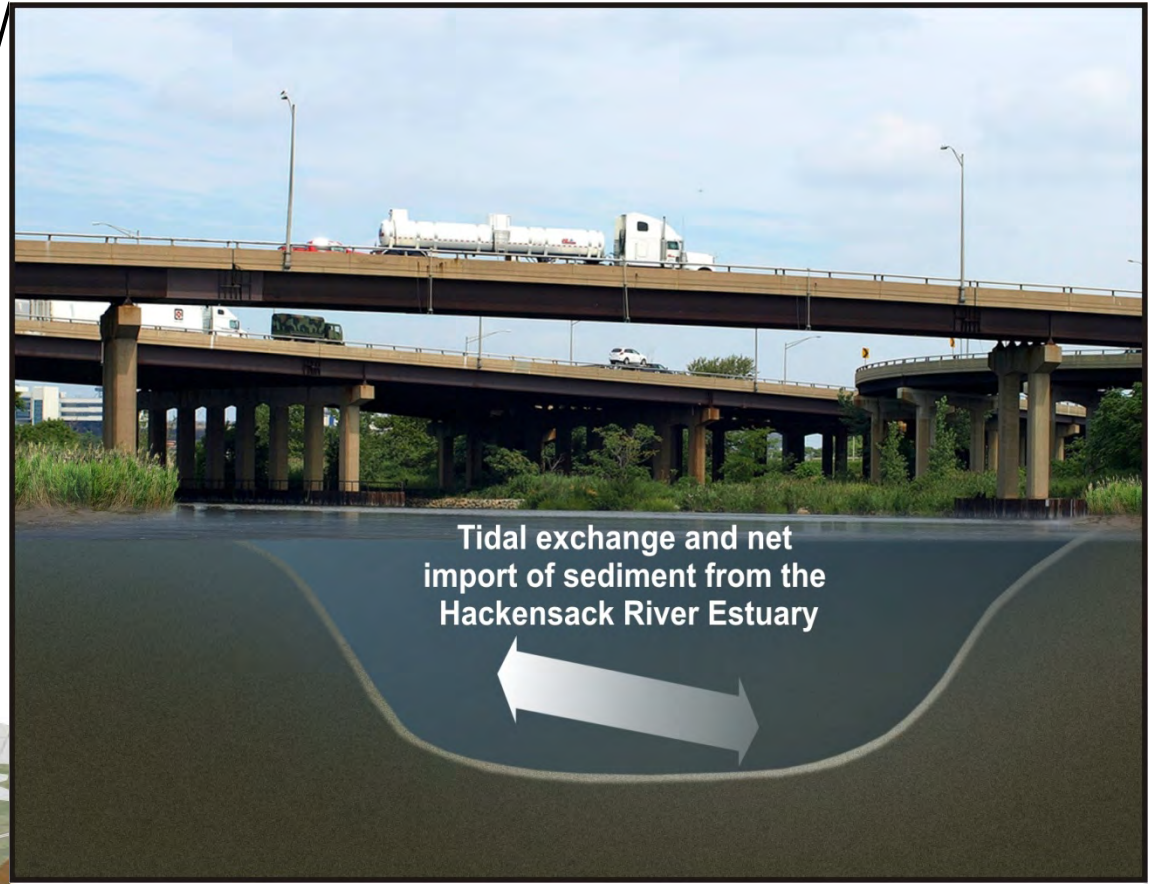
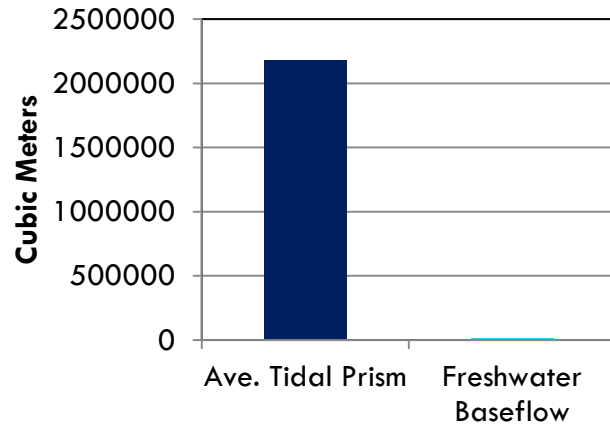


April 13, 2016 Presentation to EPA of RI Findings

Tidally Dominated, Net Depositional

16

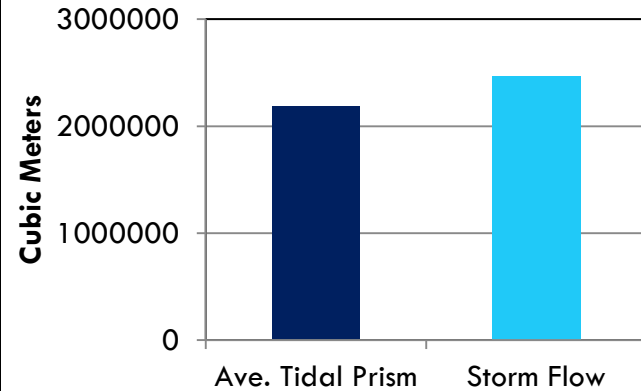
Dry Weather Flow Balance



Large Storms Result in Short-Term Modification of Flow Conditions

17

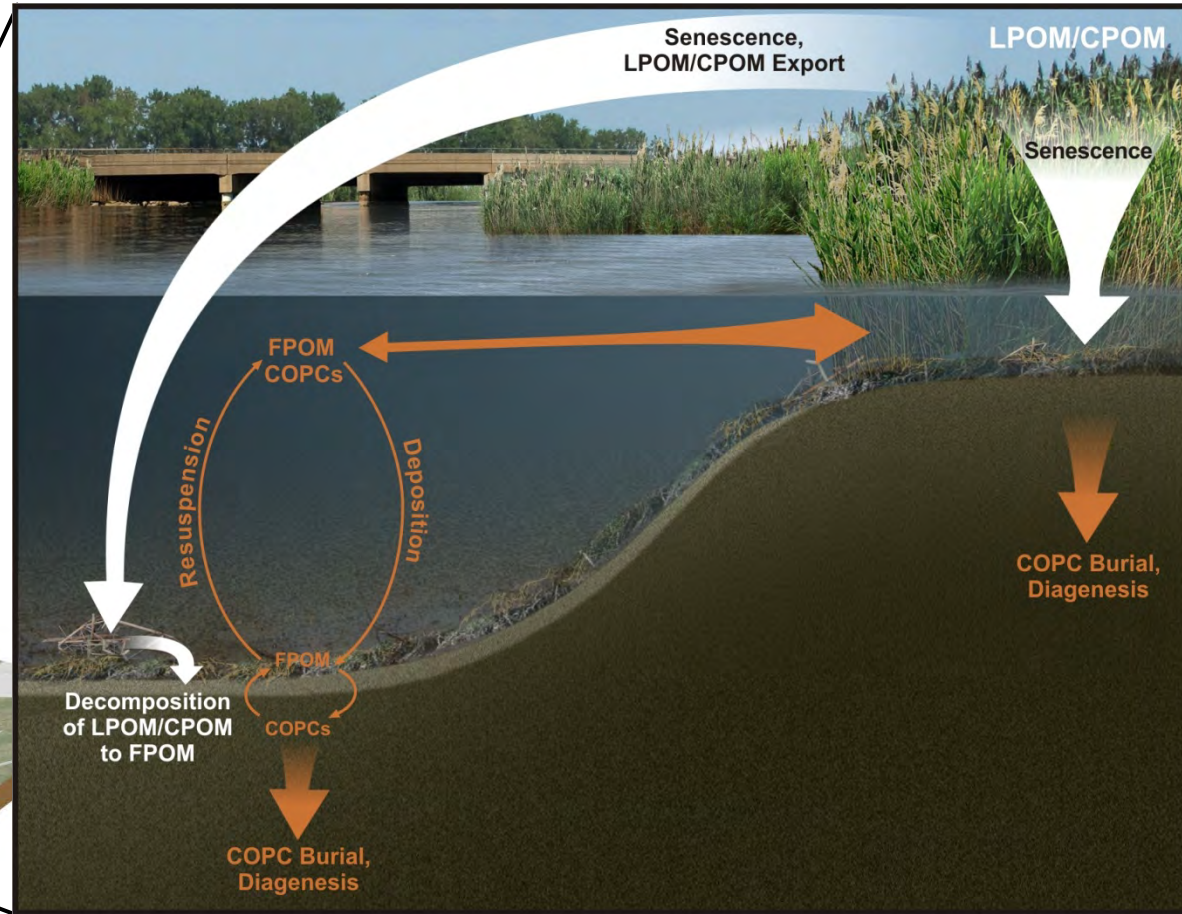
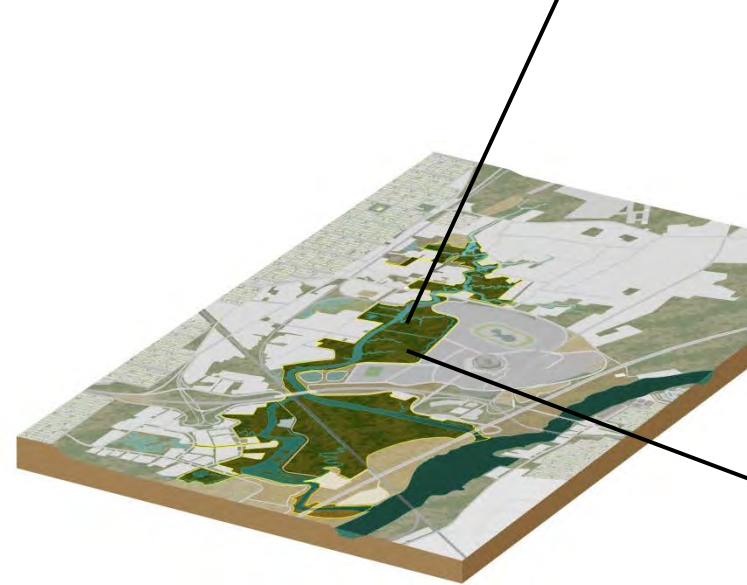
Once in 5 Year Storm Event



The Large *Phragmites* Marshes Importance

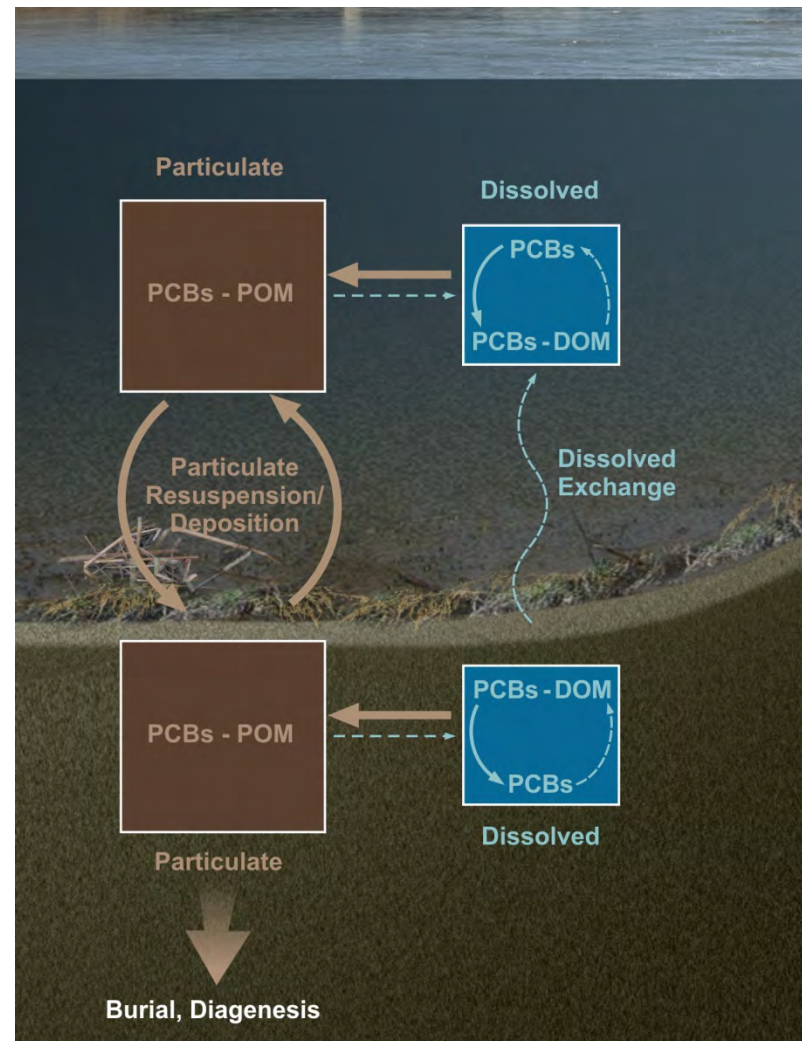
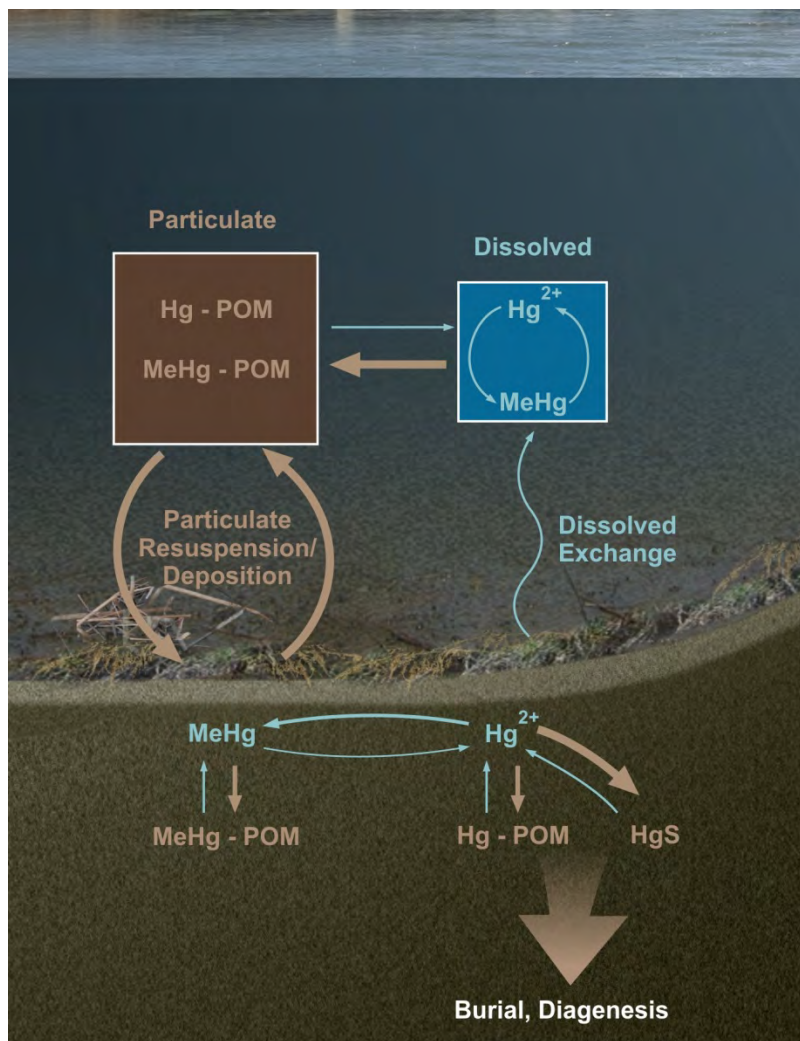
Stability, COPC Fate, Food Web Base

18



Site-Specific Chemistry CSMs

19



April 13, 2016 Presentation to EPA of RI Findings



Receptors - Waterways



Detritus

White Perch

Zooplankton

Blue Crab

Fluff Layer

Shrimp

Mummichog

Phytoplankton

Amphipod

Annelid

Phytoplankton

Zooplankton

Raccoon

Great Blue Heron

Muskrat

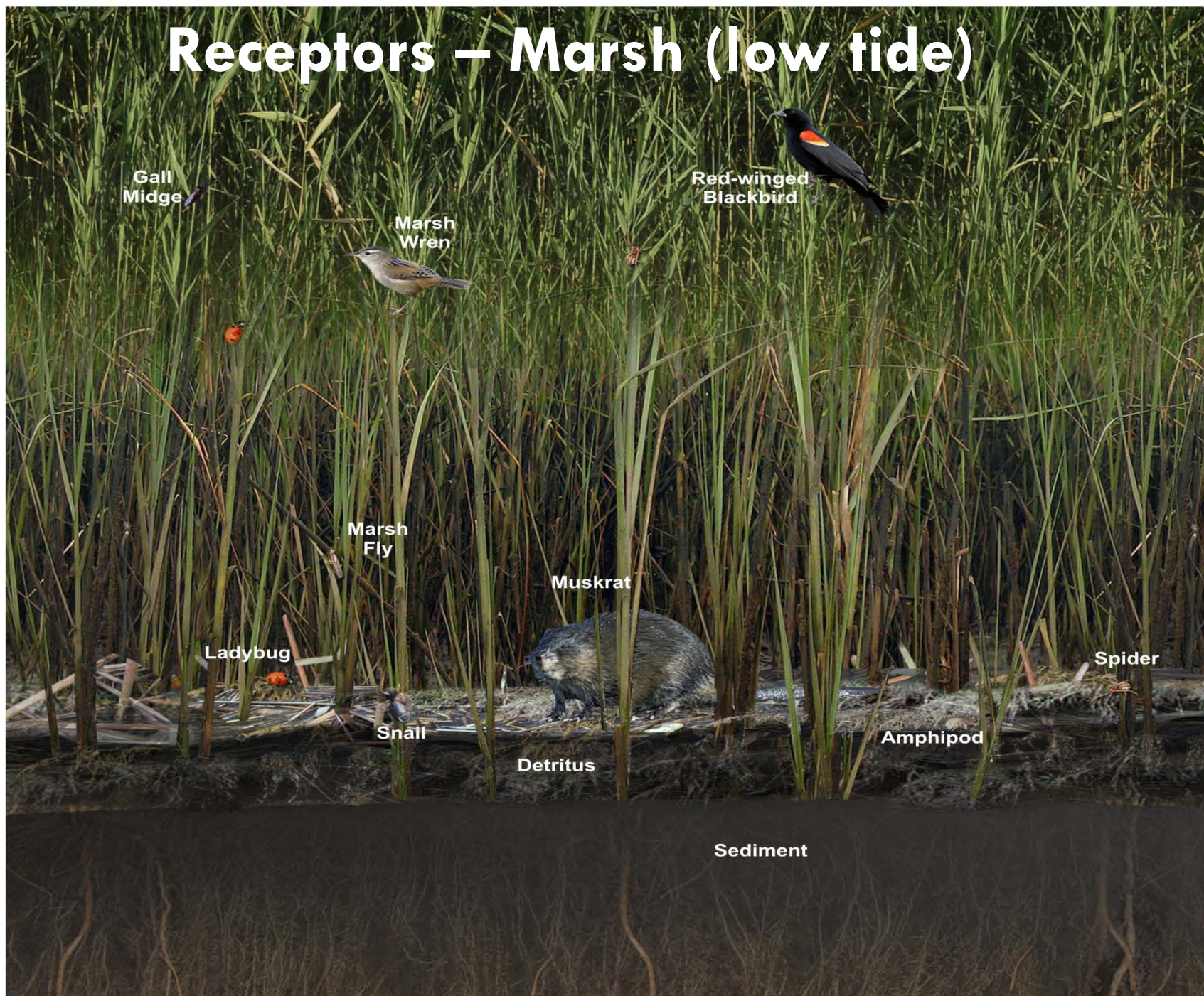
Spotted Sandpiper

Black-crowned Night Heron

Mud and Fiddler Crabs

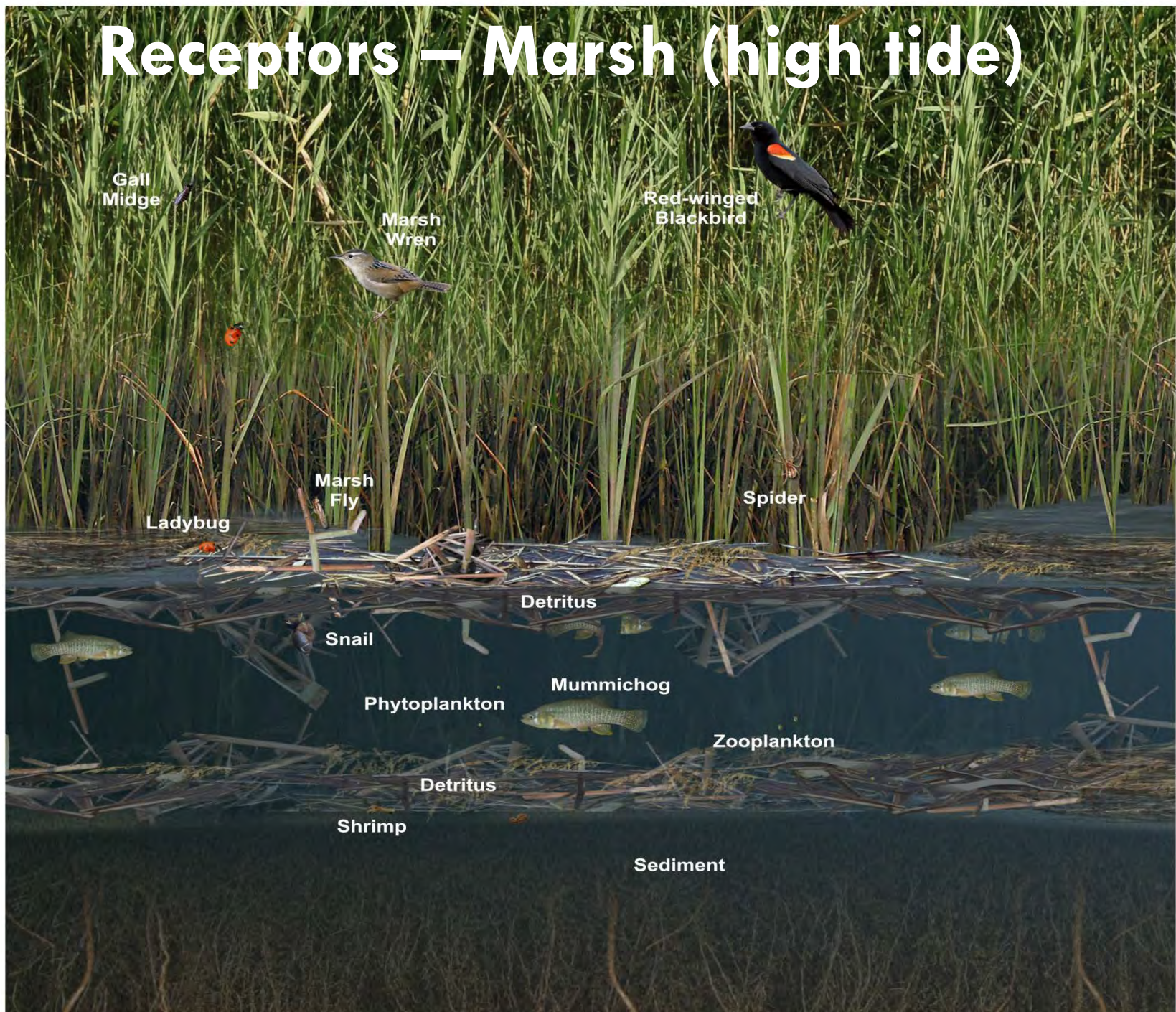
Receptors – Marsh (low tide)

21



Receptors – Marsh (high tide)

22



COPCs –

Historical & Current Sources

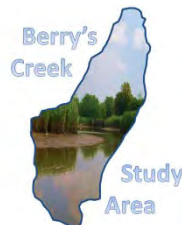
23

□ Historical sources

- ▣ Industrial facilities, sewage treatment plants, landfills, unpermitted discharges
- ▣ Majority were located in UBC and MBC

□ Current sources

- ▣ Secondary sediment sources
- ▣ Regional contributions from Hackensack River Estuary
- ▣ Unpermitted and permitted discharges
- ▣ Atmospheric deposition
- ▣ Uplands flows

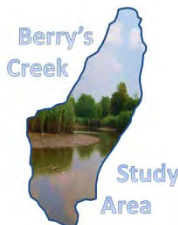


COPCs

24

- **Primary**
 - ▣ **Hg, MeHg, and PCBs**
 - ▣ **Principal risk drivers**

- **Other chemicals**
 - ▣ **Present above screening-level risk-based benchmarks**
 - ▣ **Analyzed fully in BERA and BHHRA**
 - ▣ **Add minimally to overall site risks**
 - ▣ **Largely co-occur with primary COPCs**



25

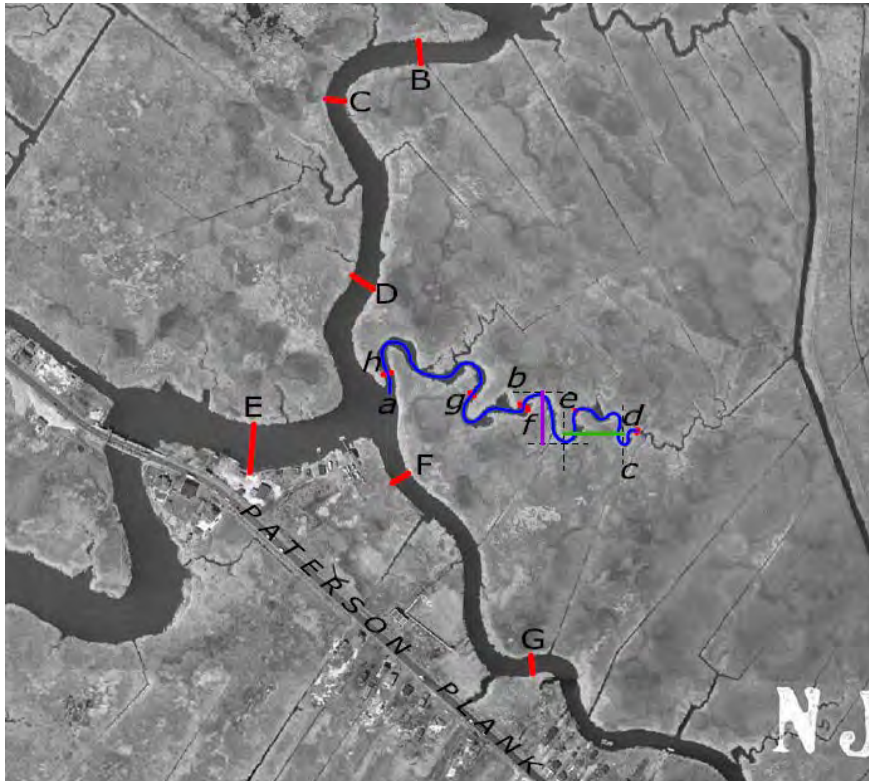
Key Finding 1

**The BCSA includes a stable net
depositional tidal area**

Stable Waterway Morphology Despite Extensive Upland Development

26

1947



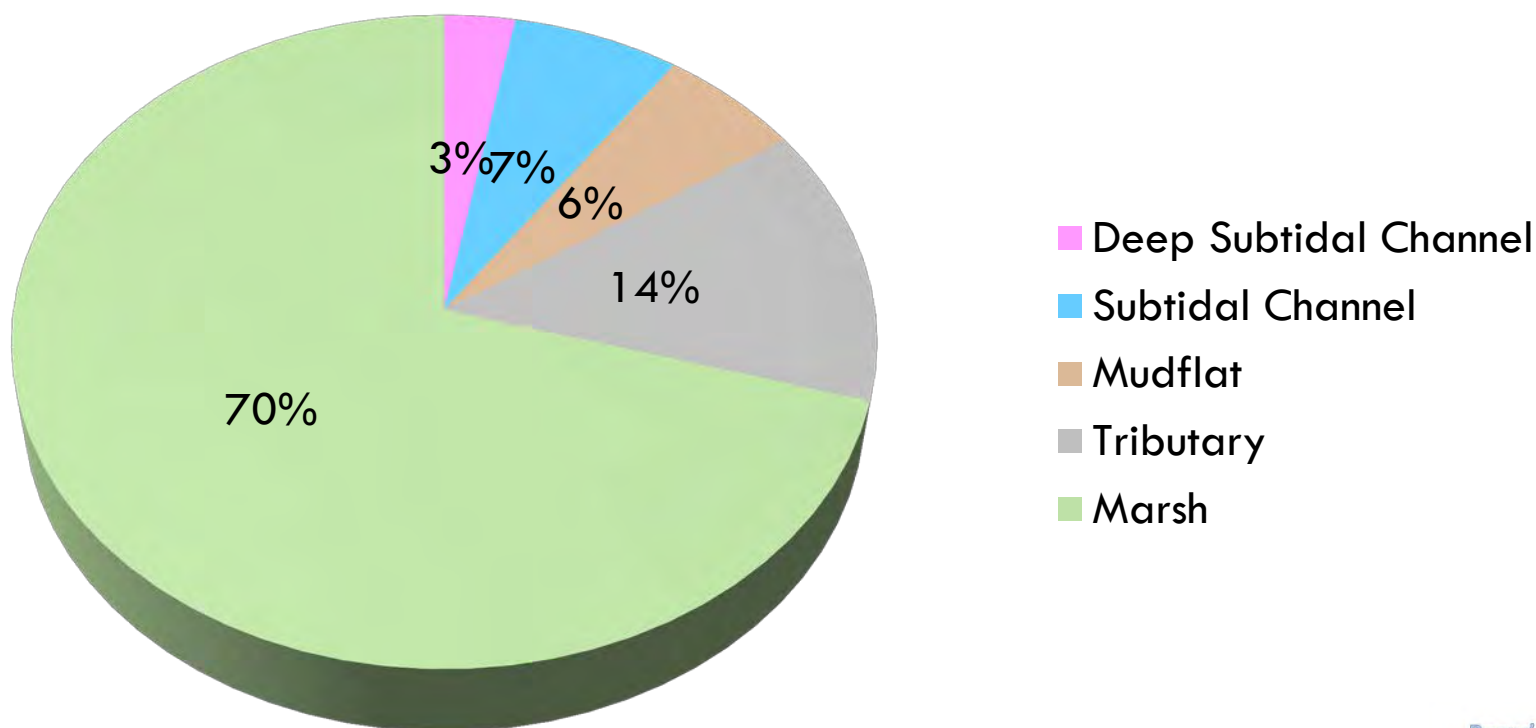
2013



Morphology of the BCSA is Characteristic of a Fringing Marsh System – Marsh Dominates

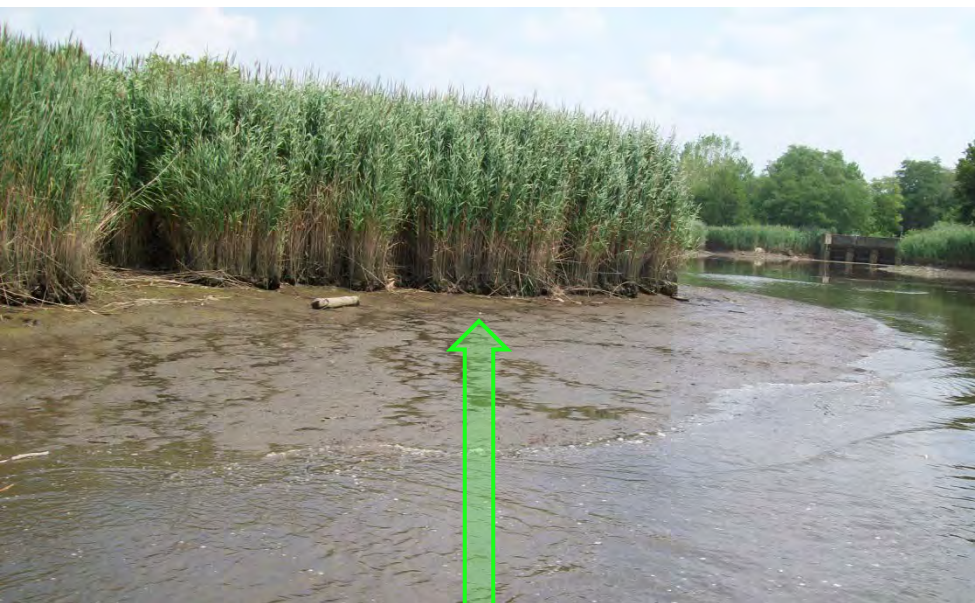
27

Percentage of BCSA Tidal Zone Represented by Each Morphology Group



Phragmites Marshes are a Key Factor Contributing to the Long-Term Stability

28



**Stable transition from
mudflat to marsh**

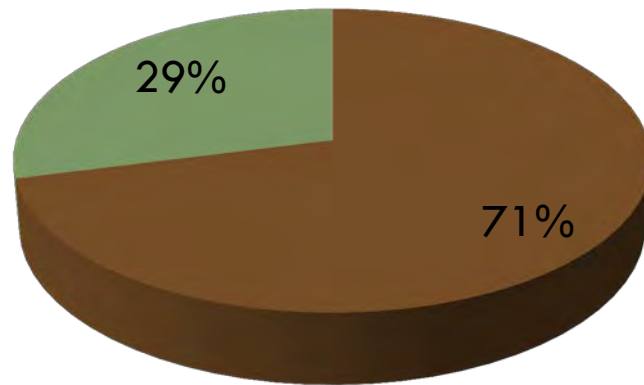
**Long term instability
when marsh system fails**



BCSA is Net Depositional and the Hackensack River is the Dominant Sediment Source

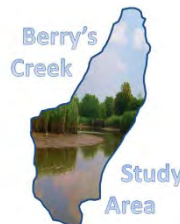
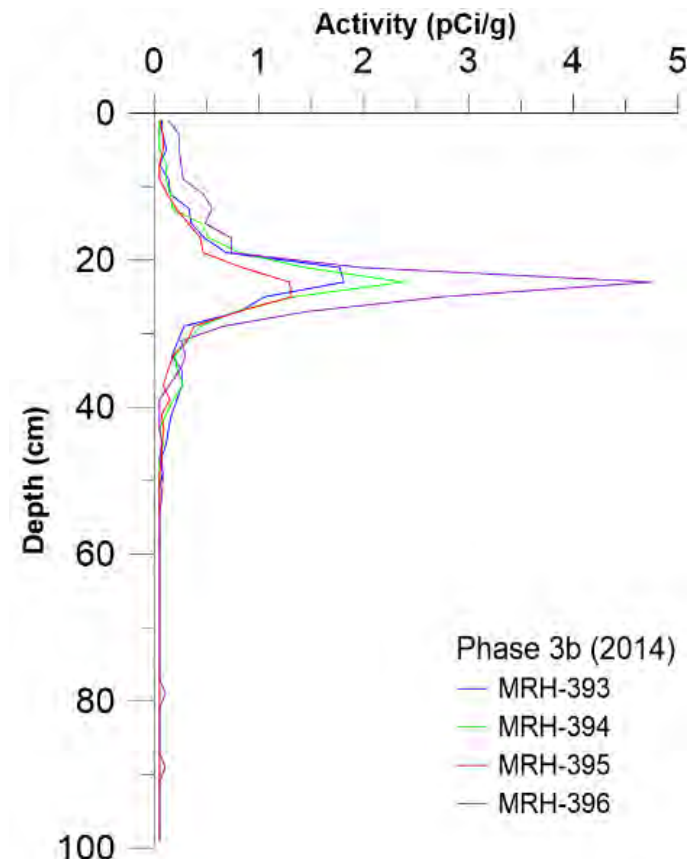
29

Sources of Inorganic Sediment to BCSA Based on Sediment Balance



■ Hackensack River Estuary ■ Uplands

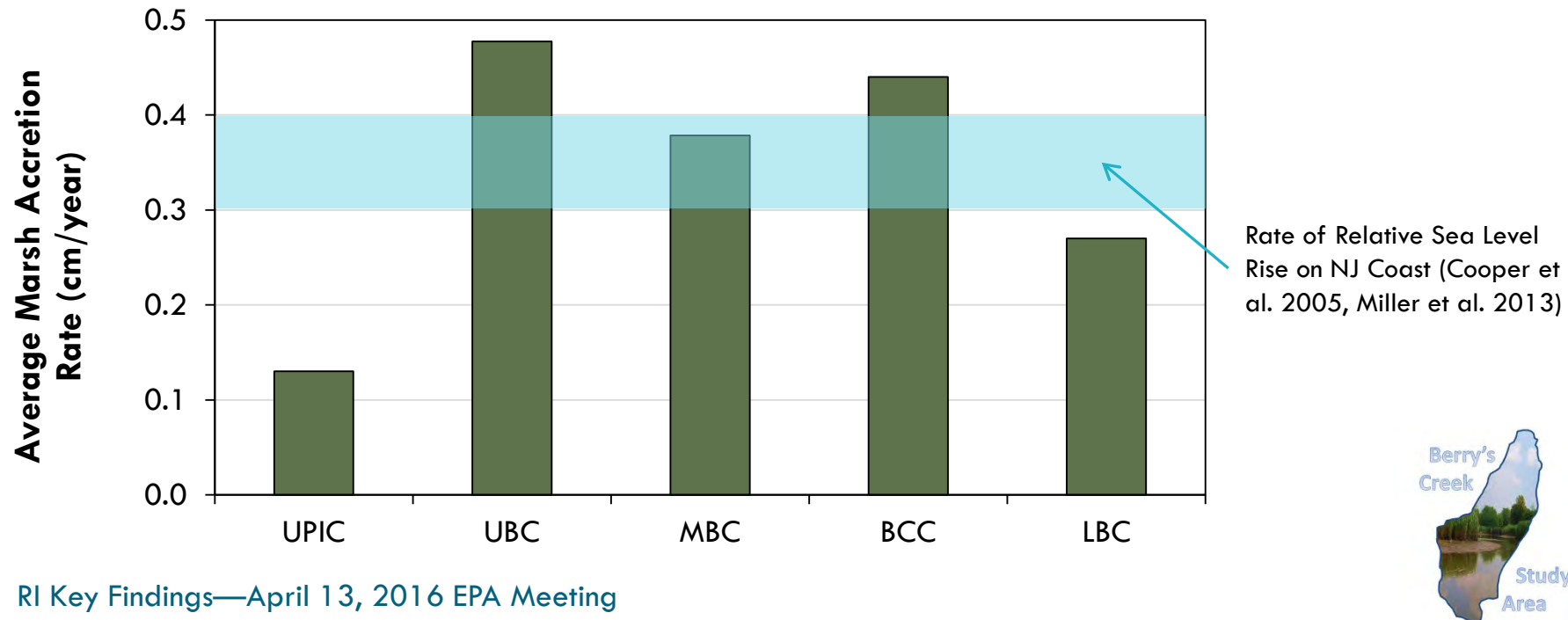
Example ^{137}Cs Results for Marsh Cores



Long-Term Sediment Dynamics

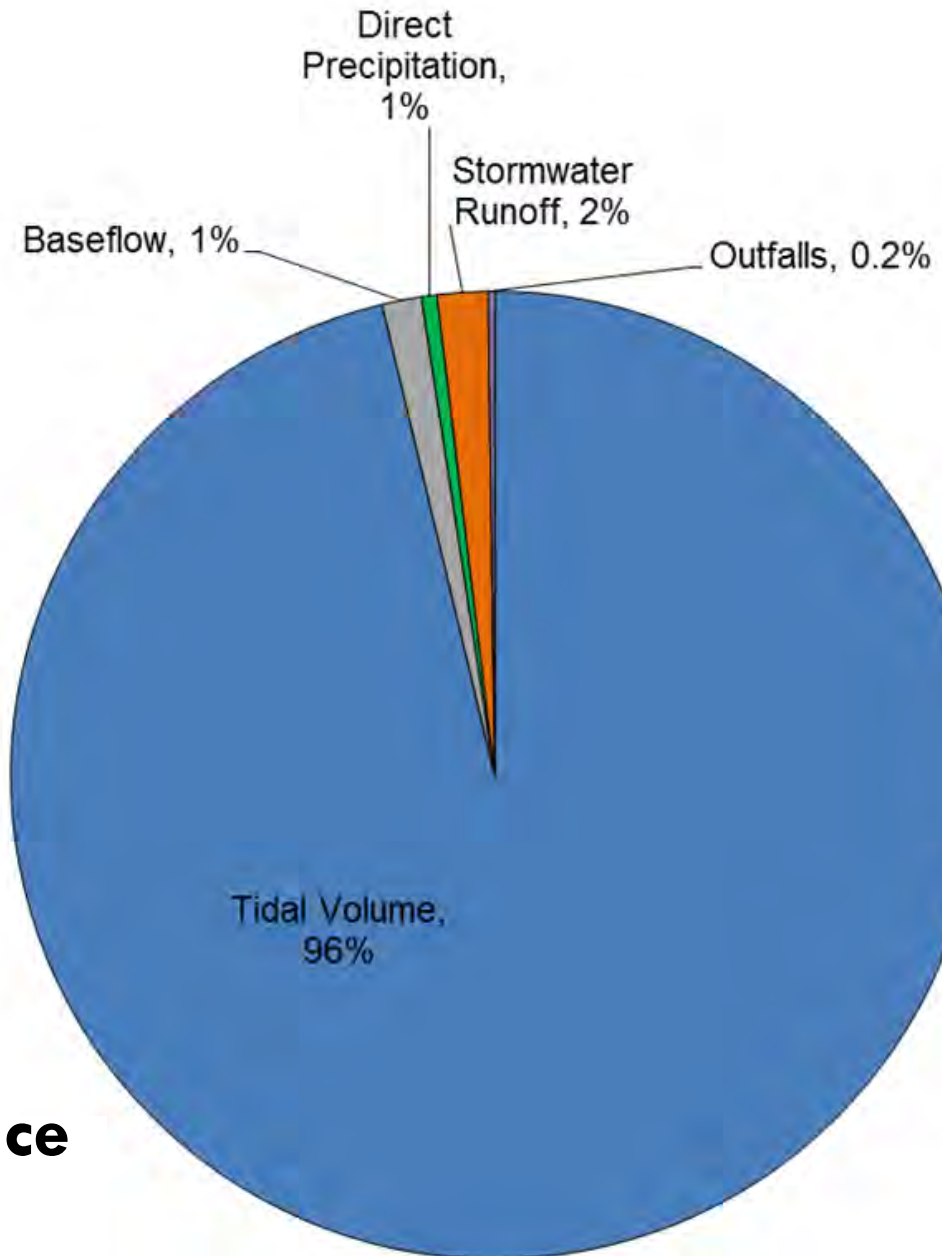
30

- **Tidal zone accretion rates similar to or greater than sea level rise**
- **Consistent with other lines of evidence**



Tidal Flow Predominates

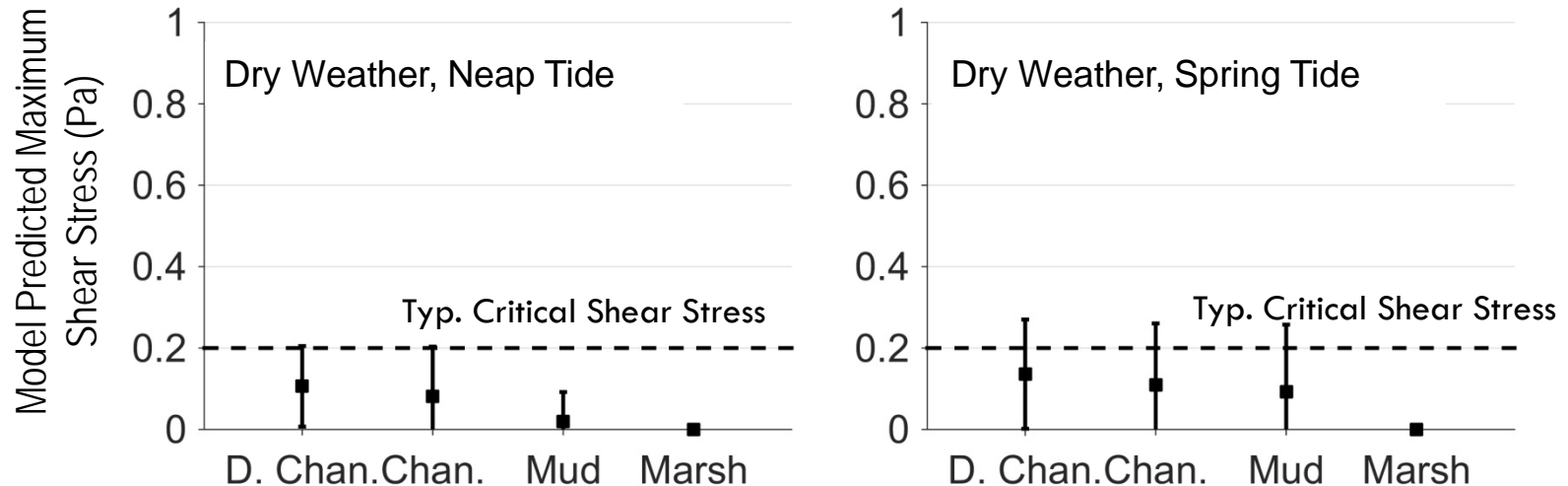
31



**Empirical Water Balance
for Full BCSA
(May 2009 – Oct 2011)**

Shear Stress Under Typical Site Conditions Is Not Sufficient to Erode Bedded Sediment

32



D. Chan. = Deep Subtidal Channel

Chan. = Subtidal Channel

Mud = Mudflat

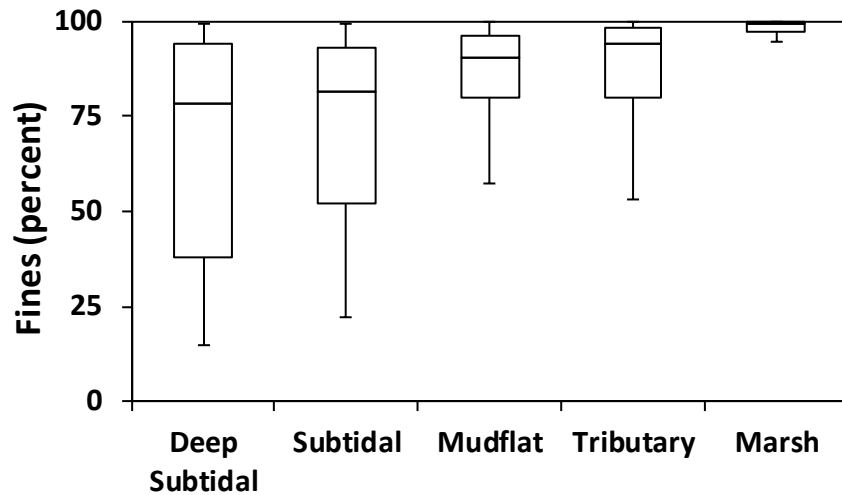
Dashed line represents the typical measured critical shear stress to erode bedded sediment in BCSA

Values are mean and ± 1 standard deviation of model-predicted maximum shear stress across all model cells within the full BCSA for each morphologic category.

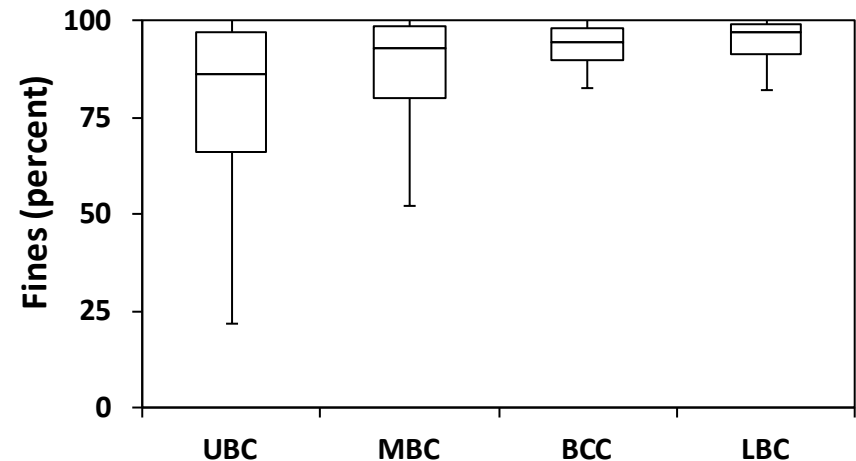
Sediment Physical Character Reflects the System Energy Regime

33

Increasing energy and increasing
coarse grained sediment



Increasing uplands influence and increasing
coarse grained sediment

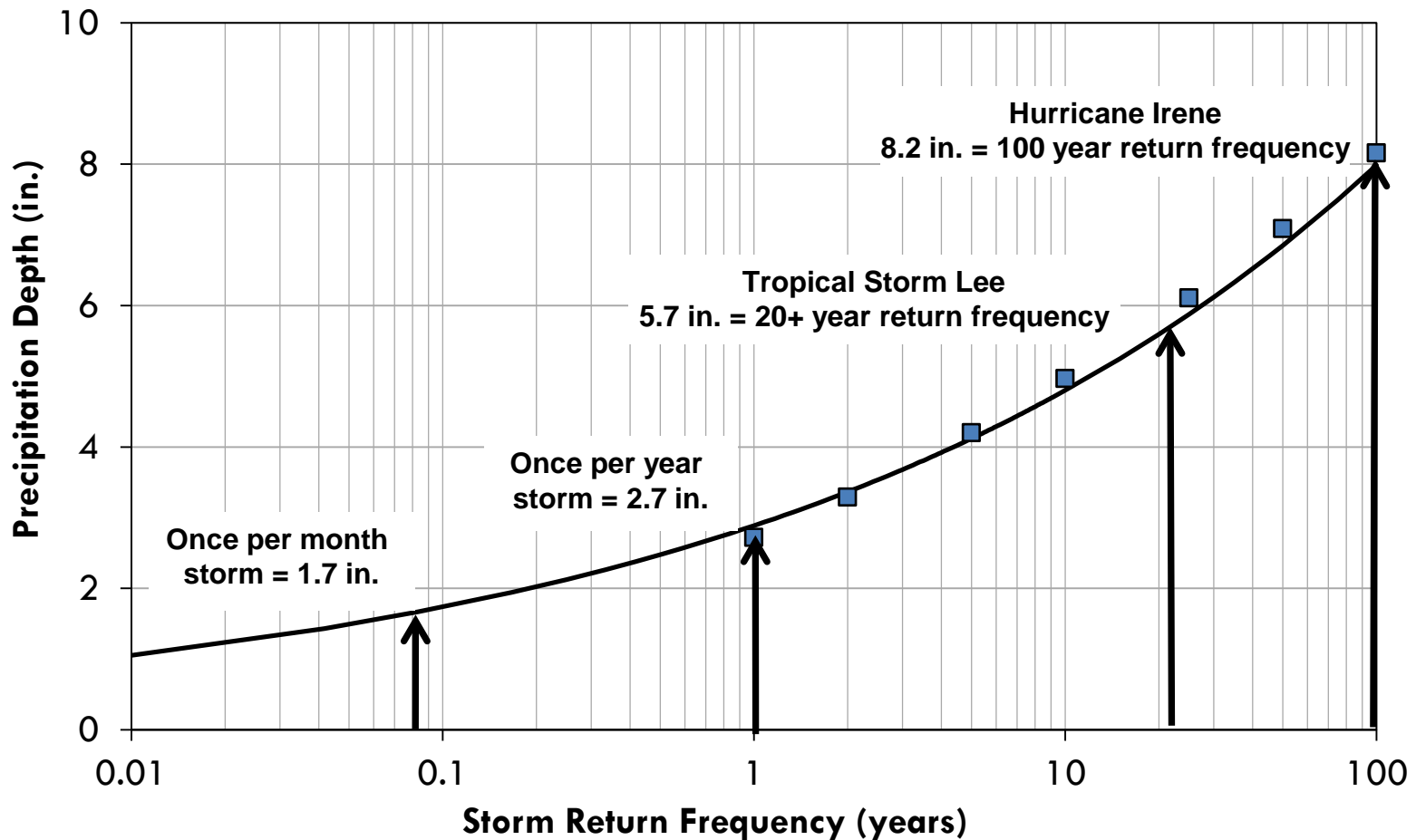


Grain size data from sediment samples collected throughout the BCSA



Major Storm Events are Infrequent

34

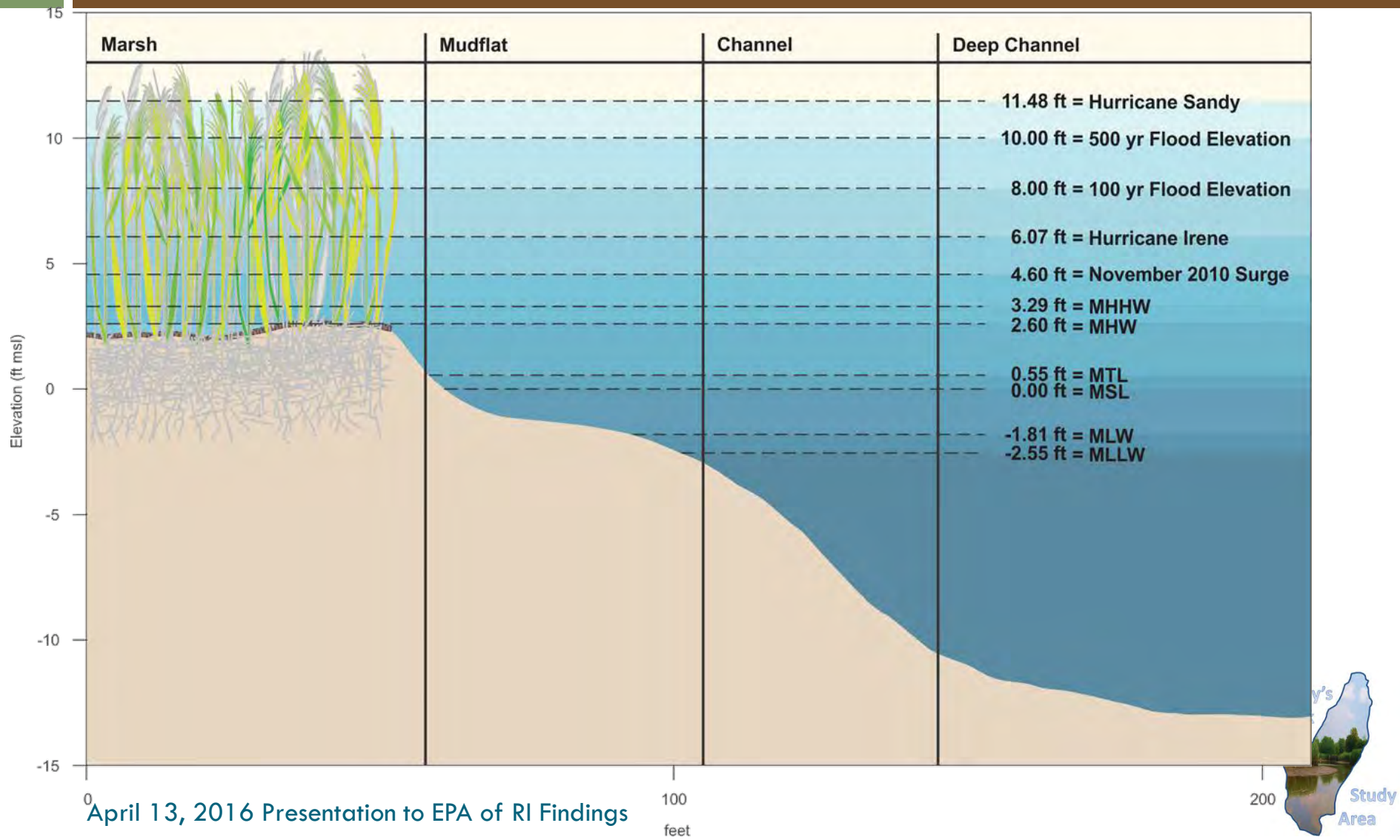


NOAA Atlas 14 program for Jersey City, NJ (Bonnin et al. 2006)



The Tidal Surge During Hurricane Sandy Surpassed the 500-Year Flood Stage

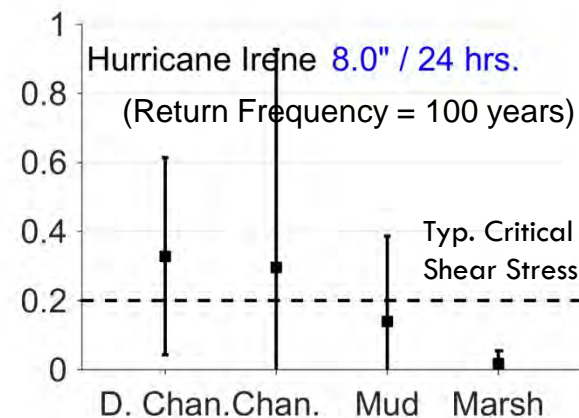
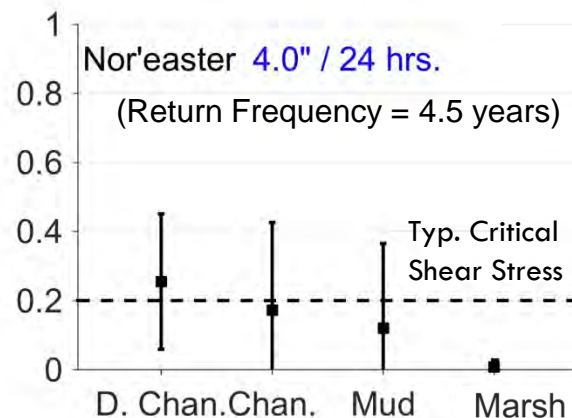
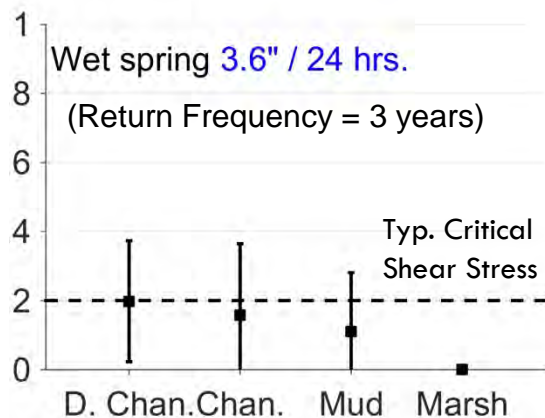
35



Infrequent Large Storm Events Can Result In Localized Resuspension of Subtidal Bedded Sediment

36

Model Predicted Maximum Shear Stress (Pa)



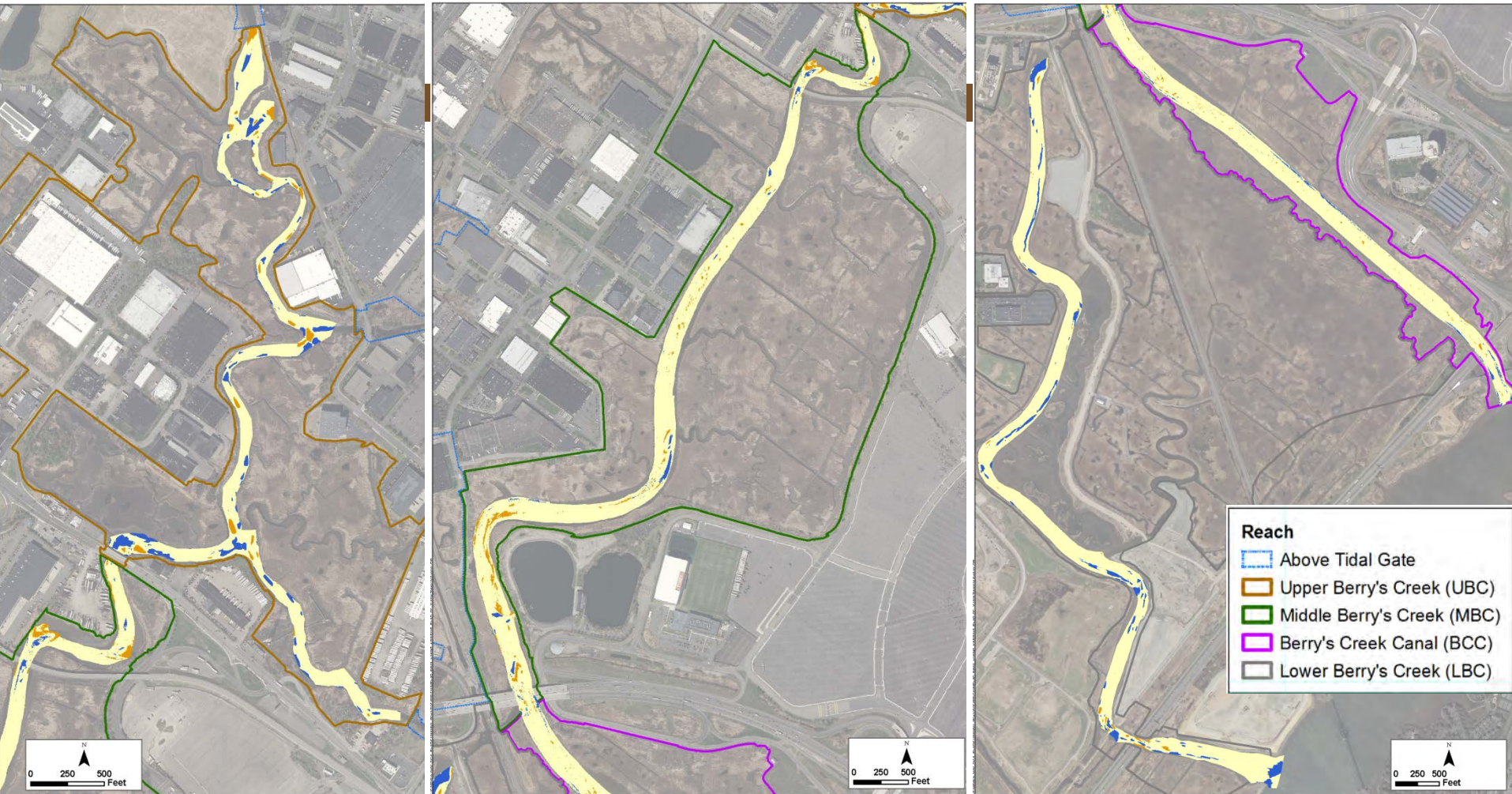
D. Chan. = Deep Subtidal Channel
 Chan. = Subtidal Channel
 Mud = Mudflat
 Mar. = Marsh

Dashed line represents the typical measured critical shear stress to erode bedded sediment in BCSA

Values are mean and ± 1 standard deviation of model-predicted maximum shear stress across all model cells within the full BCSA for each morphologic category.

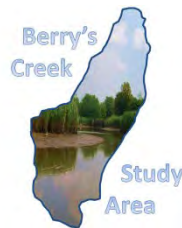


Comparison of the 2014 and 2008 Bathymetric Surveys



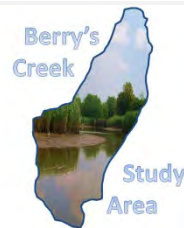
Legend	Net Change	Waterway Area
	No change	91%
	Deepening	6%
	Shoaling	3%

April 13, 2016 Presentation to EPA of RI Findings



Key Finding 2

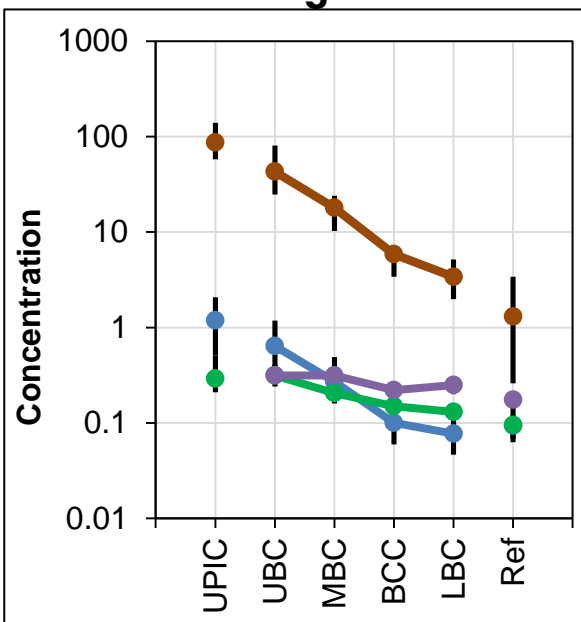
COPC concentrations are substantially higher in the northern end of the study area



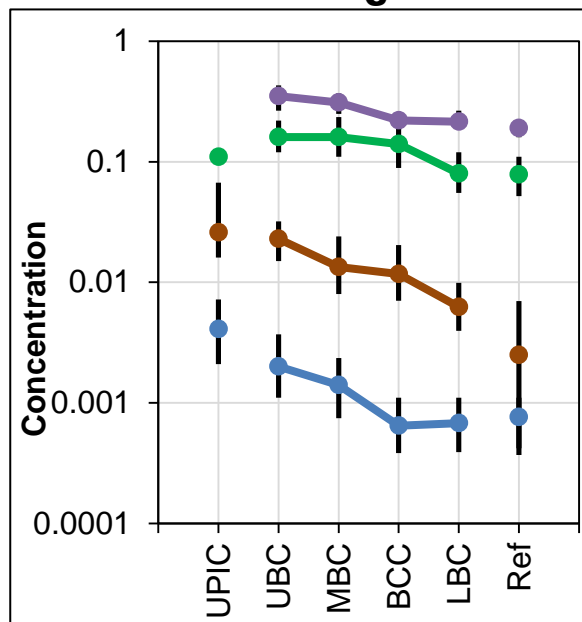
Consistent Spatial Patterns Observed Across Abiotic and Biotic Media

39

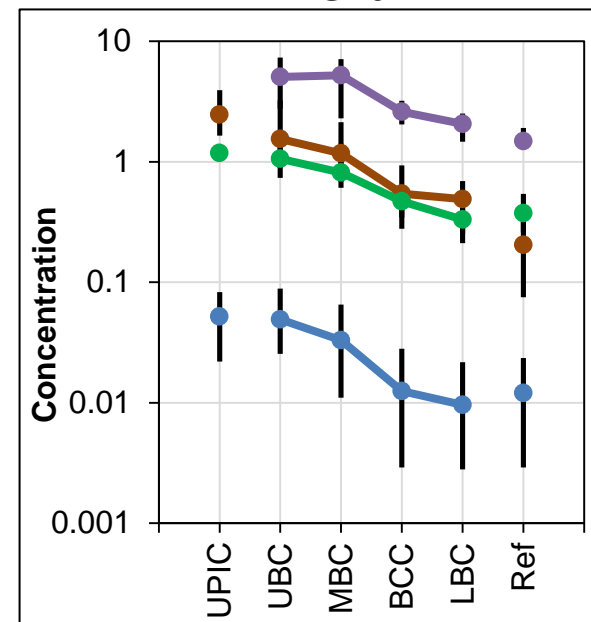
Hg



MeHg



PCBs



- BAZ Sediment (mg/kg)
- Surface Water (mg/L)
- Mummichog Whole Body (mg/kg)
- White Perch Whole Body (mg/kg)

Plot presents median concentration and 25th/75th percentiles
Surface water data are for unfiltered (total) samples.

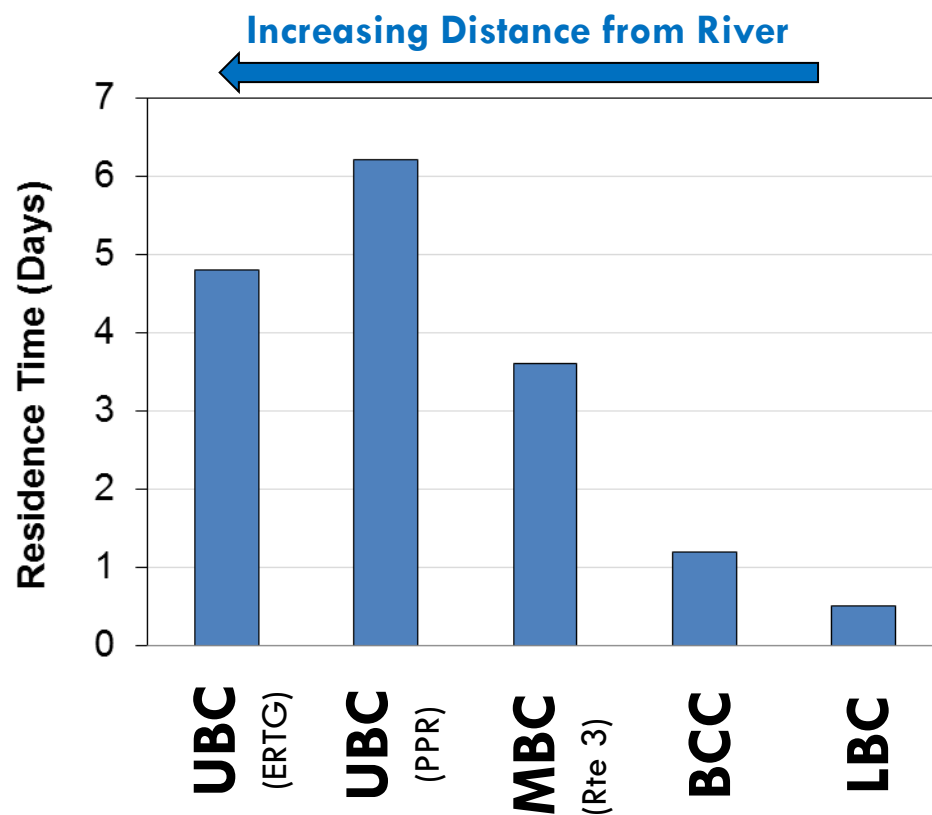


Contaminant Distribution is Consistent with Historical Sources and BCSA Hydrodynamics

40

- **Majority of historical sources in UBC and MBC**
- **Long residence time of the UBC and MBC facilitated accumulation of COPCs from these sources in UBC/MBC sediment**

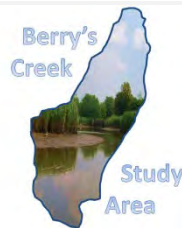
Model-Predicted Residence Time (Based on Water Age)



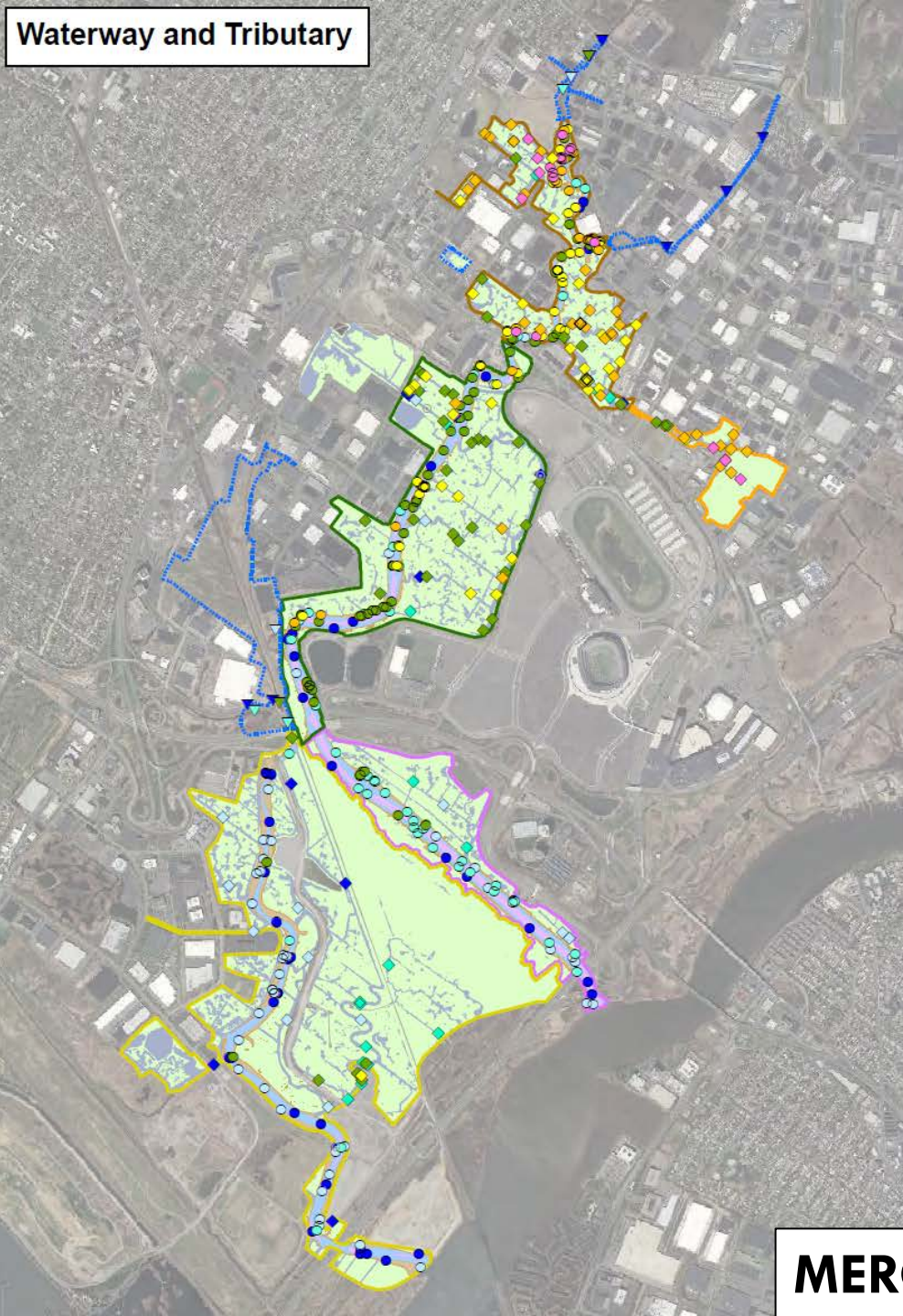
41

COPC Distribution

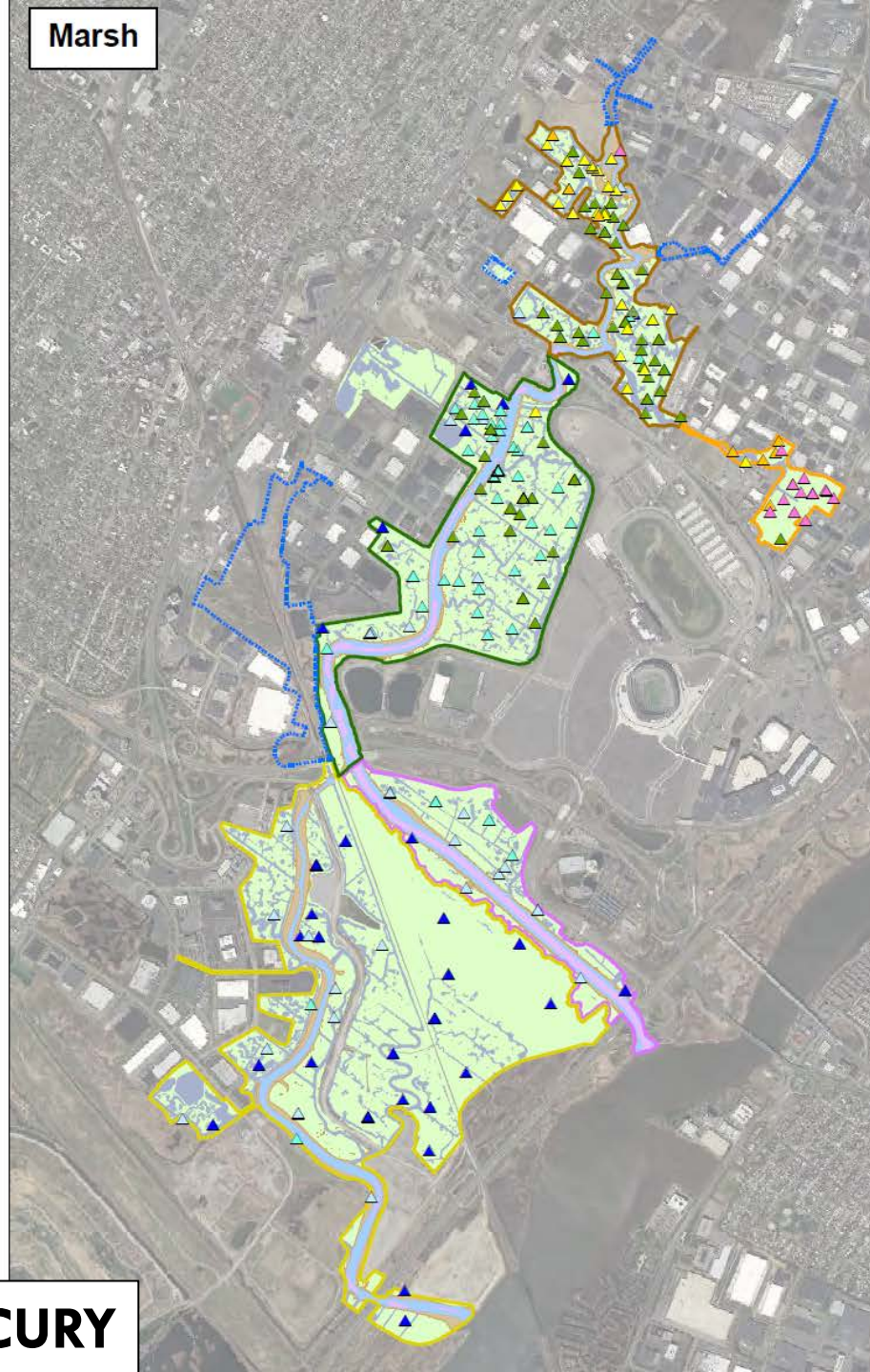
Refer to Handouts



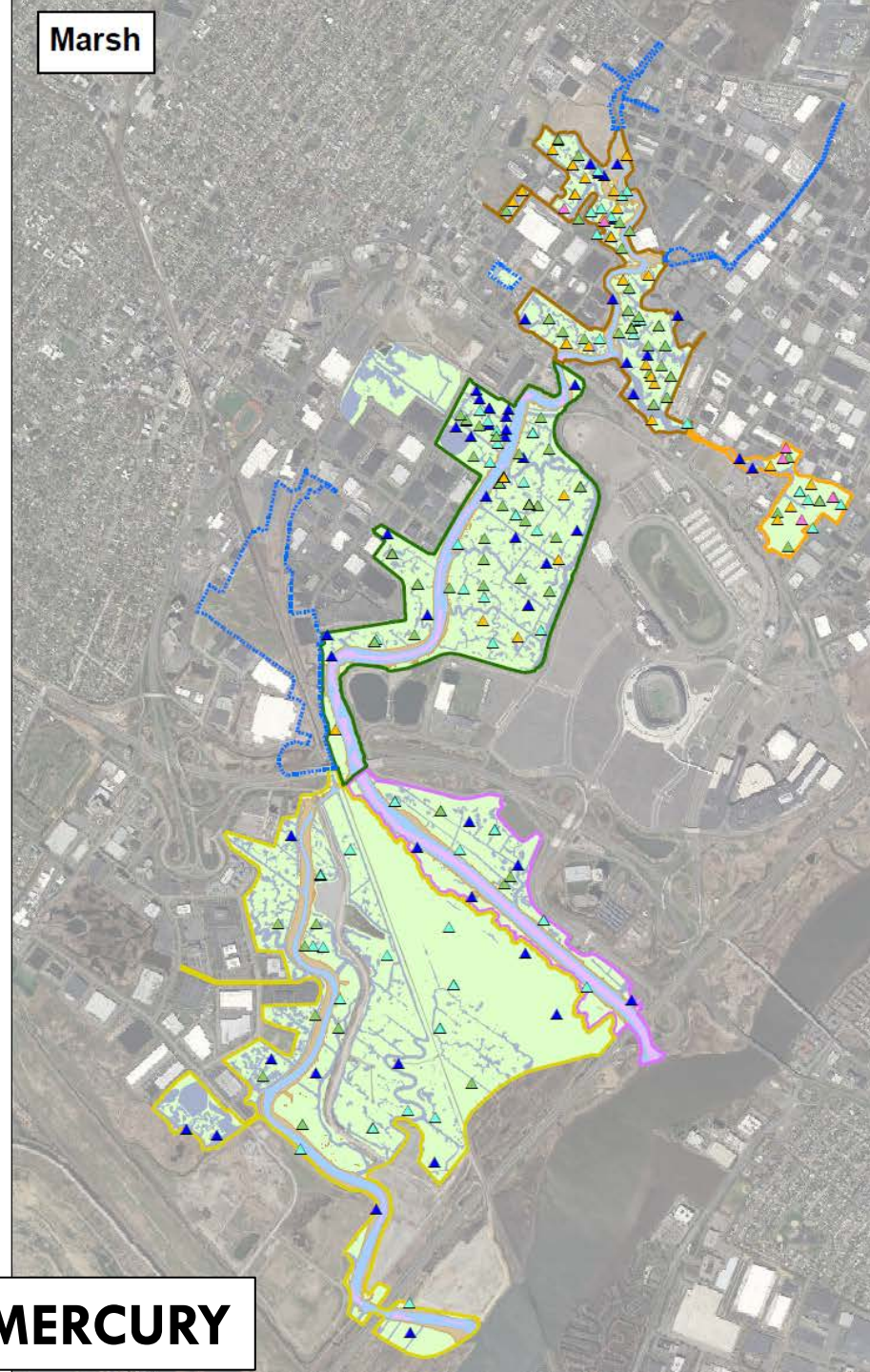
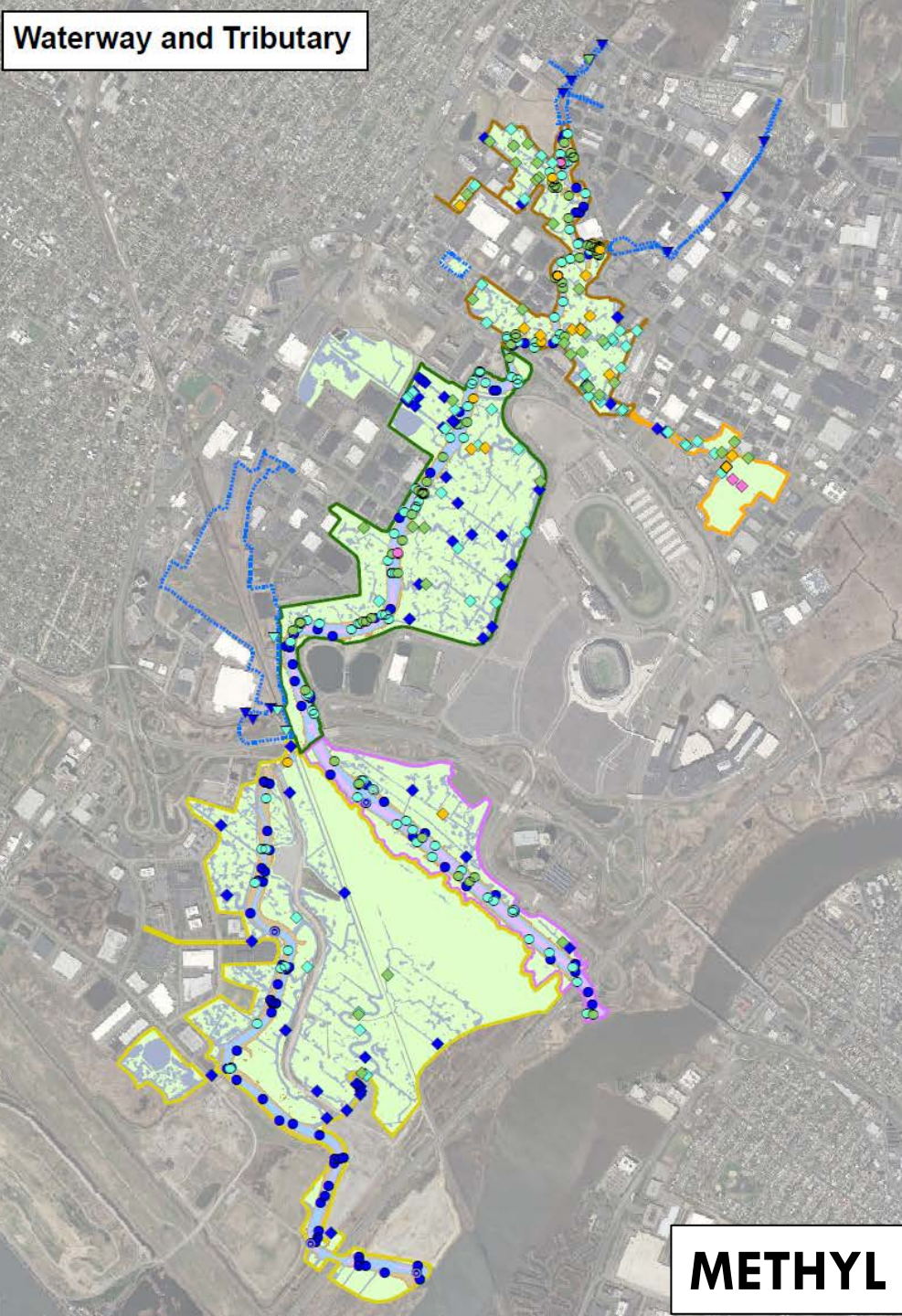
Waterway and Tributary



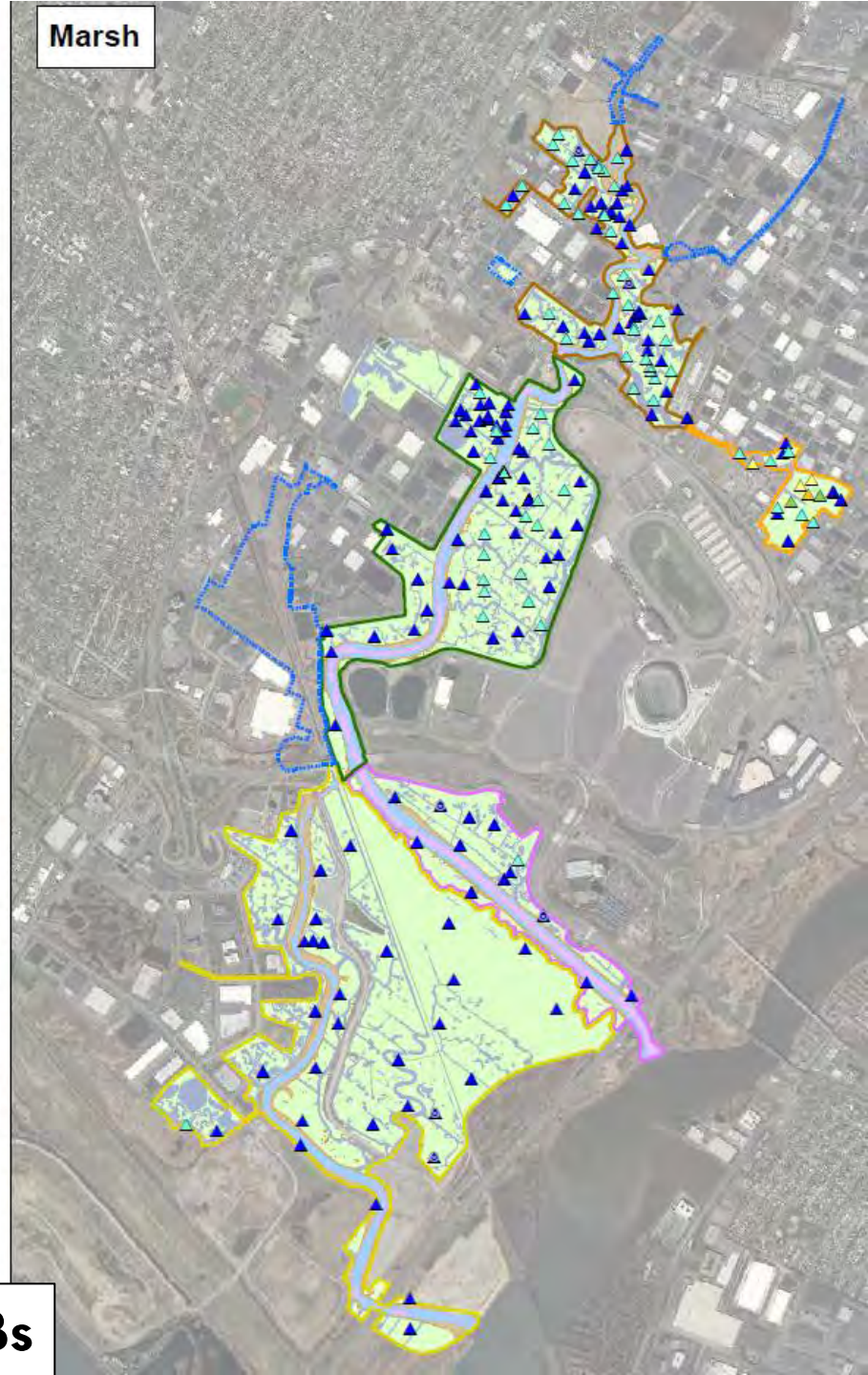
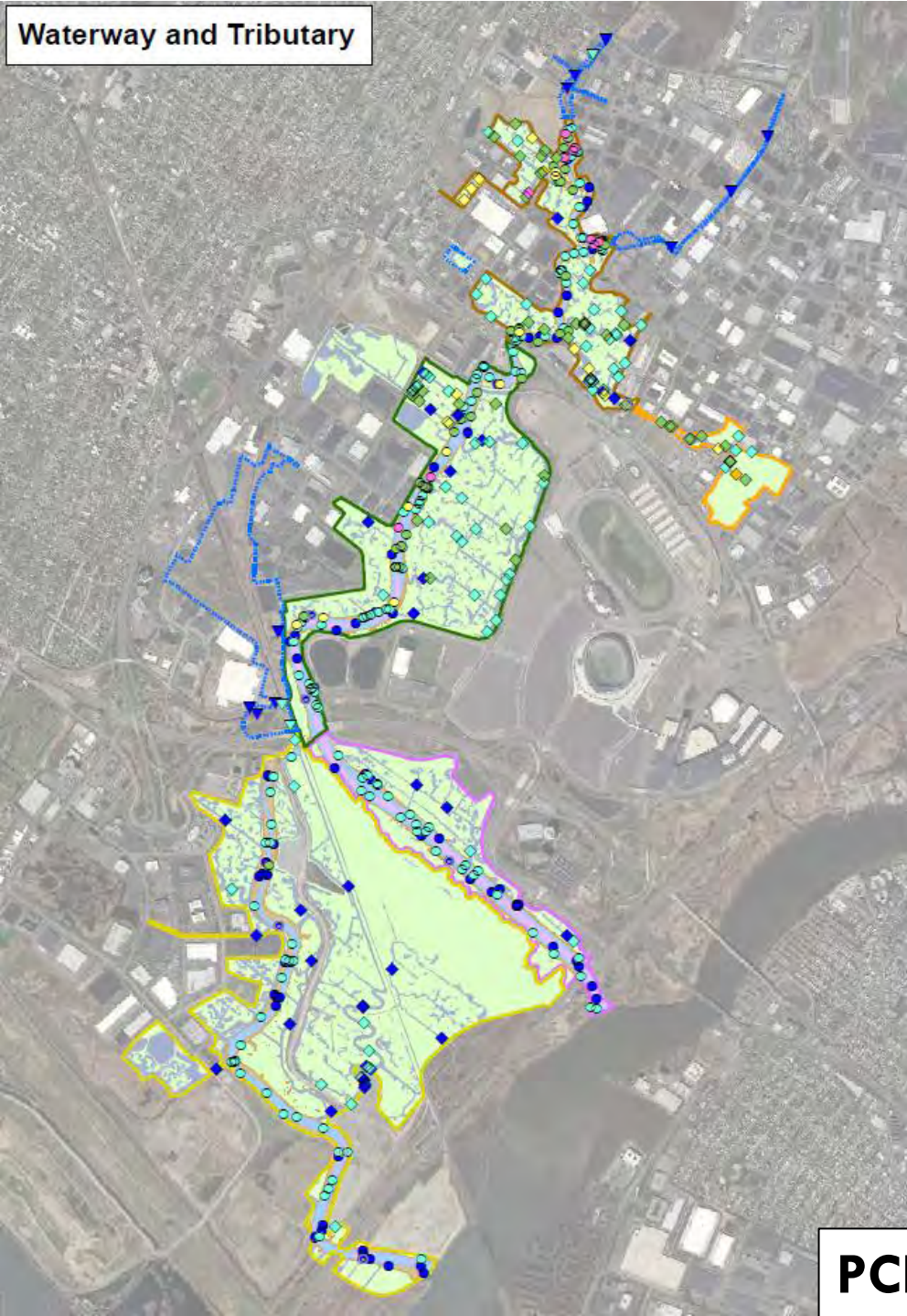
Marsh



MERCURY

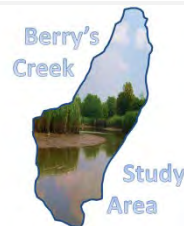


METHYL MERCURY



Key Finding 3

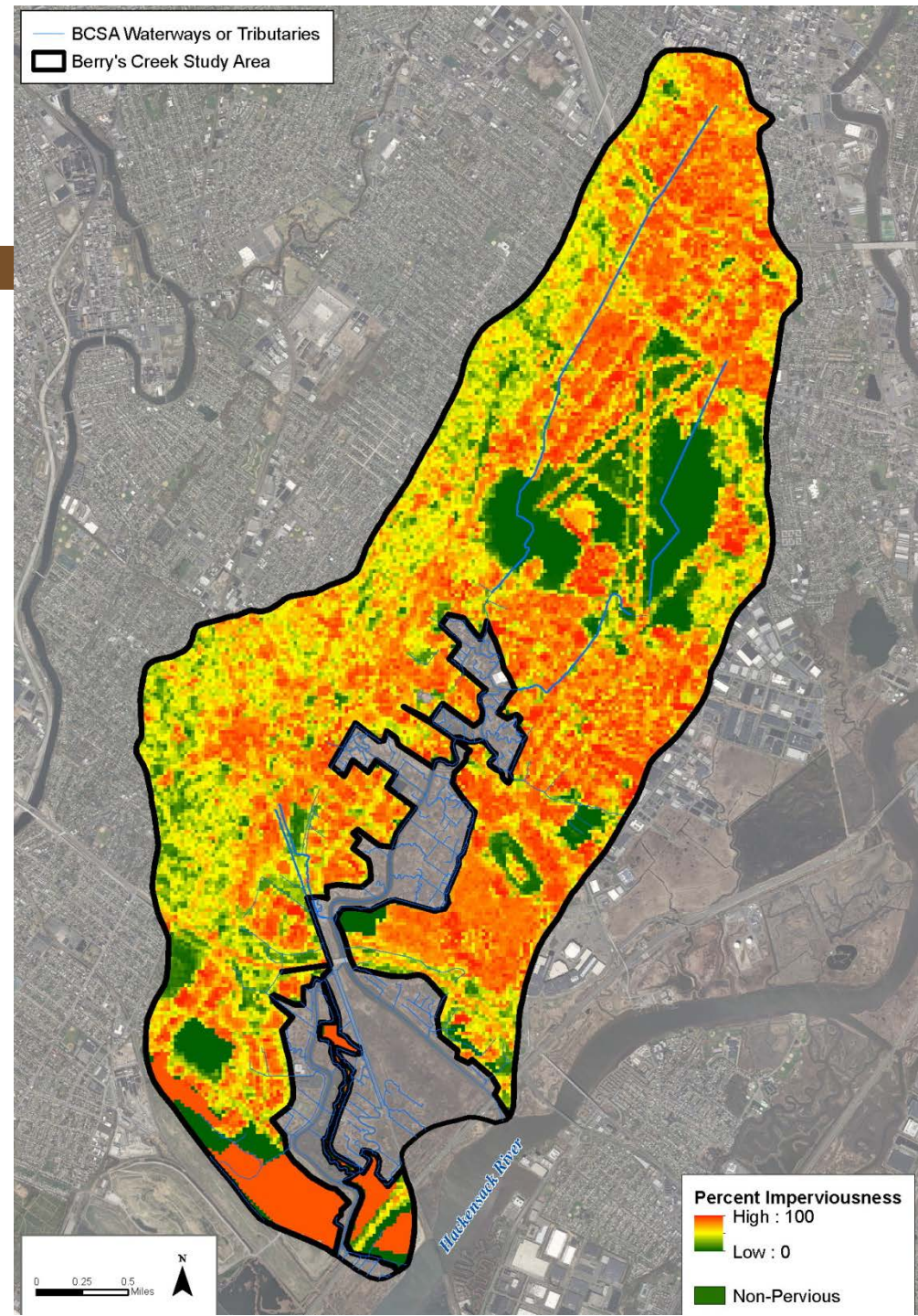
The urban setting has altered the physical, chemical, and biological character of BCSA, which is distinctly different from non-urban areas



Highly-Developed Urban Watershed

46

- Upland over 95% developed land
- Over 50% of the uplands is impervious surfaces
- Overall, aquatic environment stressed by urban land use



Anthropogenic Activity Has Modified the Region and the BCSA

47

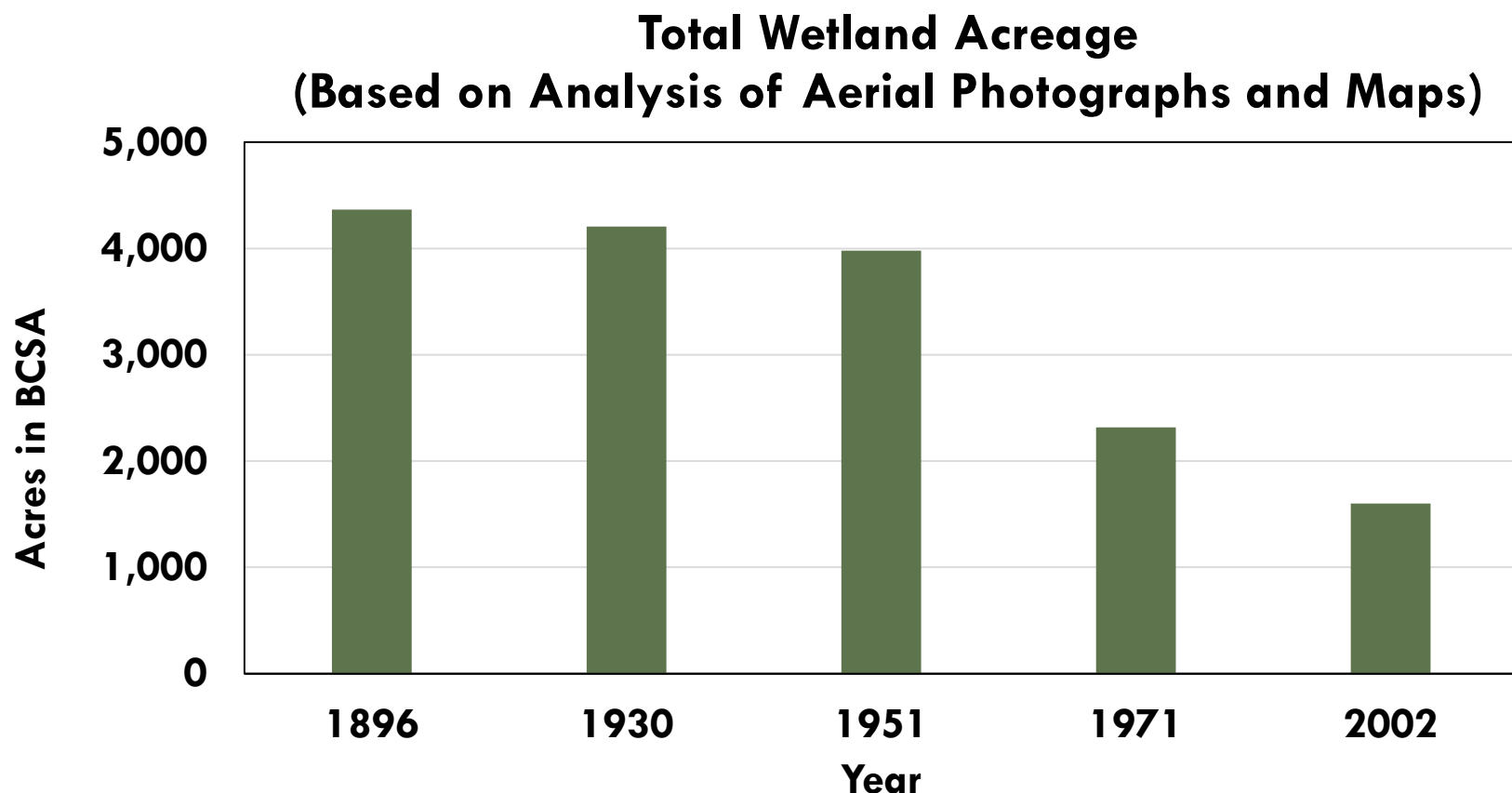
- ❑ **Land development**
- ❑ **Hydrologic modifications**
- ❑ **Modification to sediment sources to the estuary**
- ❑ **Waste management practices**
 - ▣ **Sewage effluent – fine particulates**
 - ▣ **Combined sewers – pathogens**

Oradell Dam



Extensive Filling of BCSA Wetlands

48

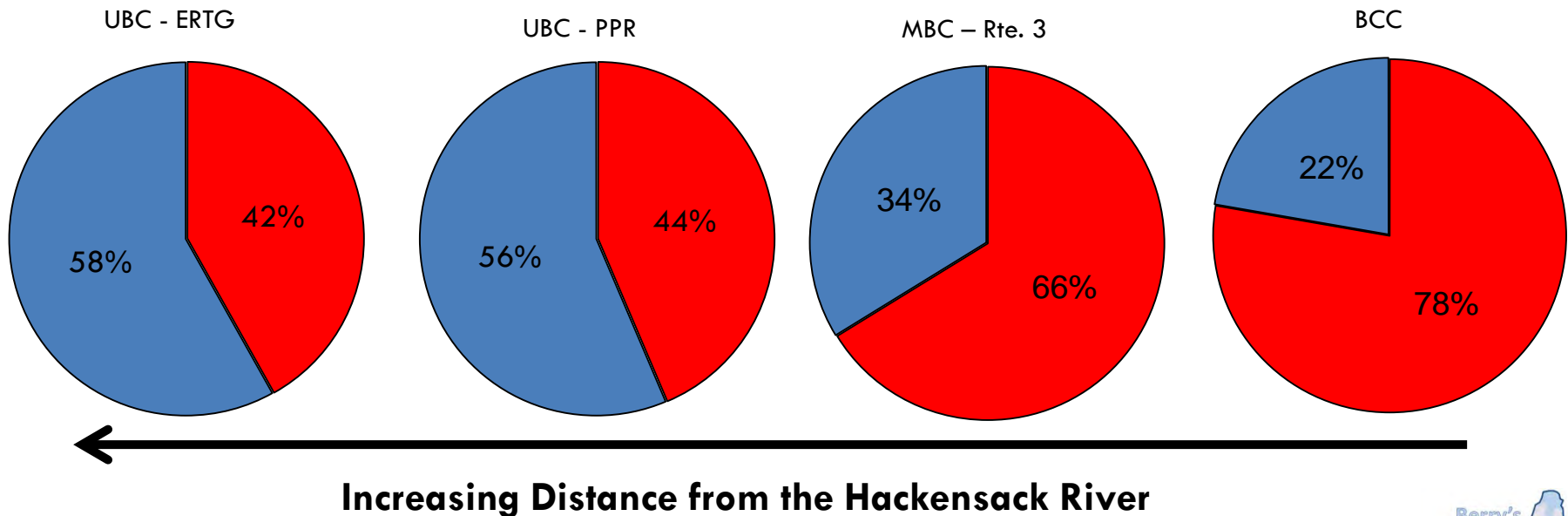


Regional Water Quality Impacts on BCSA

49

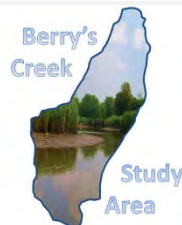
Dissolved Oxygen frequently below NJ Standard of 5 mg/L during warm months

DO > Threshold —  — DO < Threshold



Key Findings 4 - 6

- 4. Most COPC concentrations are lower at the sediment surface and are substantially higher at depth**
- 5. Natural recovery is occurring in the waterways, though variable in magnitude due to occasional episodic re-working and resuspension of near surface sediment in localized areas**
- 6. Marsh natural recovery is substantial and consistent, and is linked to sediment and COPC inputs from waterways**

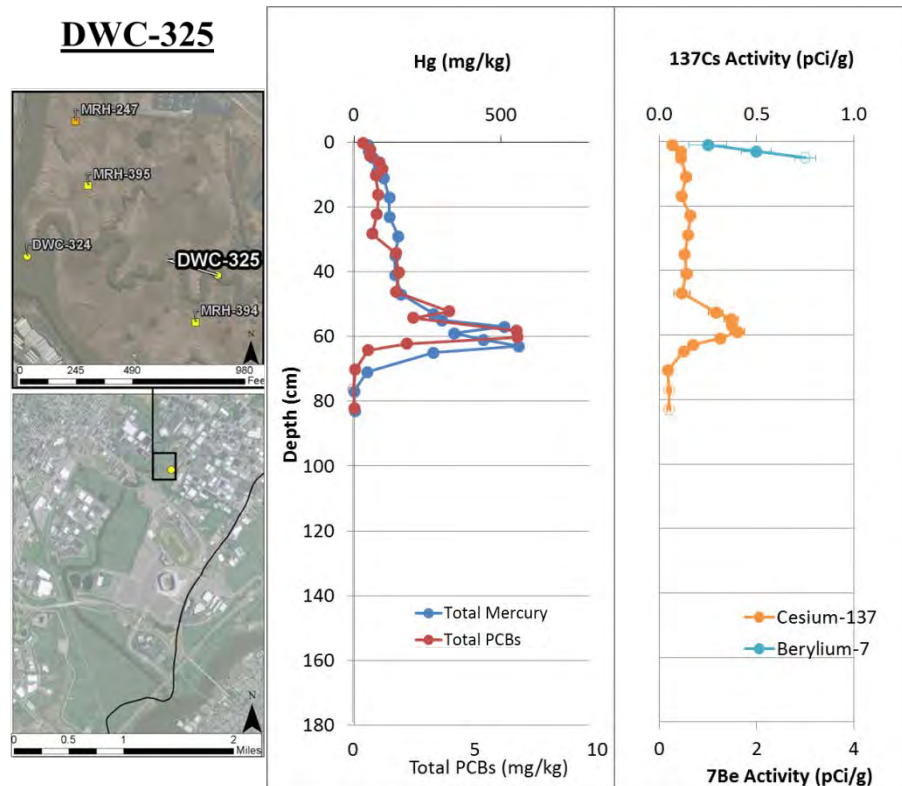


Majority of Waterway Cores Show Strong Natural Recovery with Evidence of Episodic Reworking in Some Cores

51

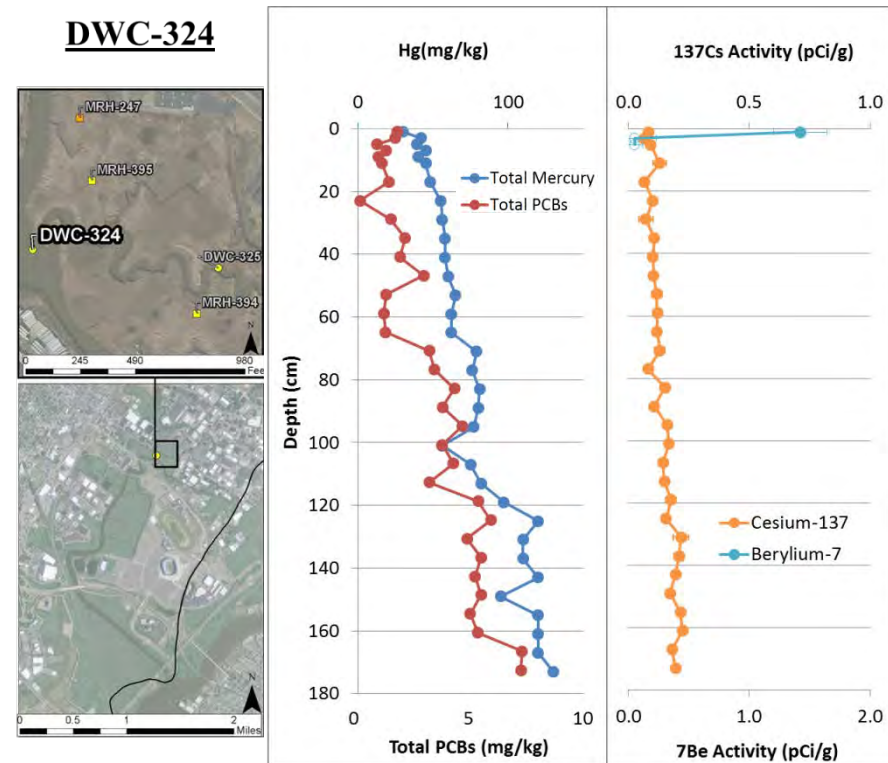
Example Waterway Core Showing Consistent Deposition

DWC-325



Example Waterway Core Showing Recovery and Episodic Reworking

DWC-324

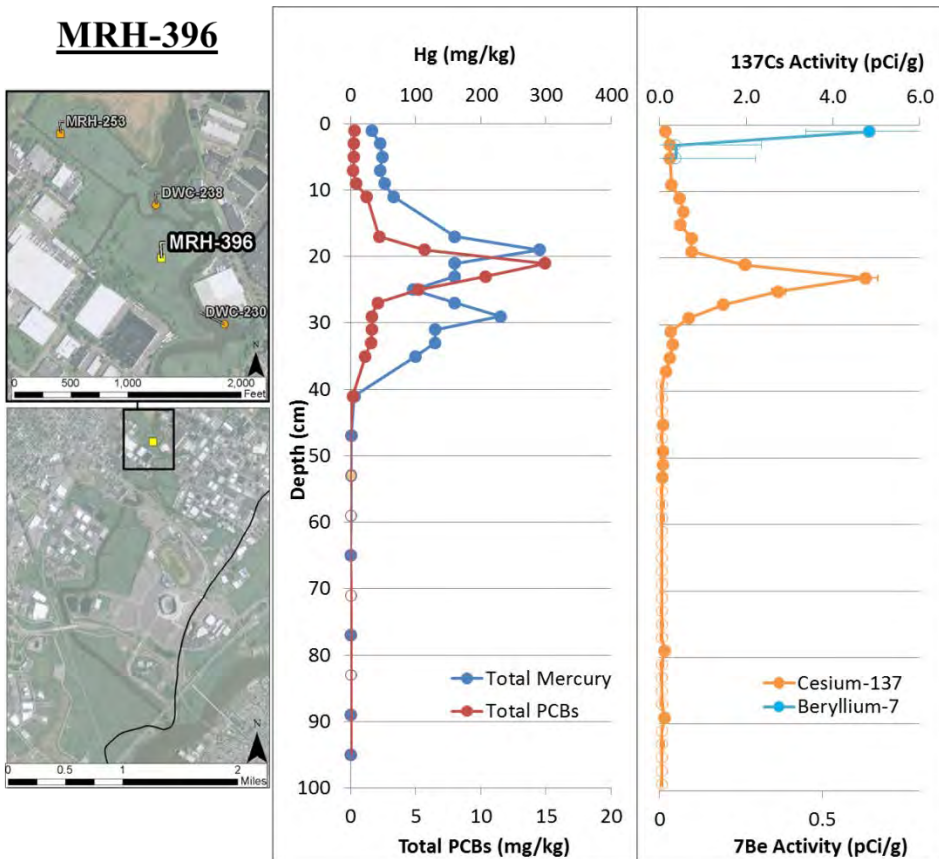


Marsh Natural Recovery is Substantial and Consistent within a Given Marsh

52

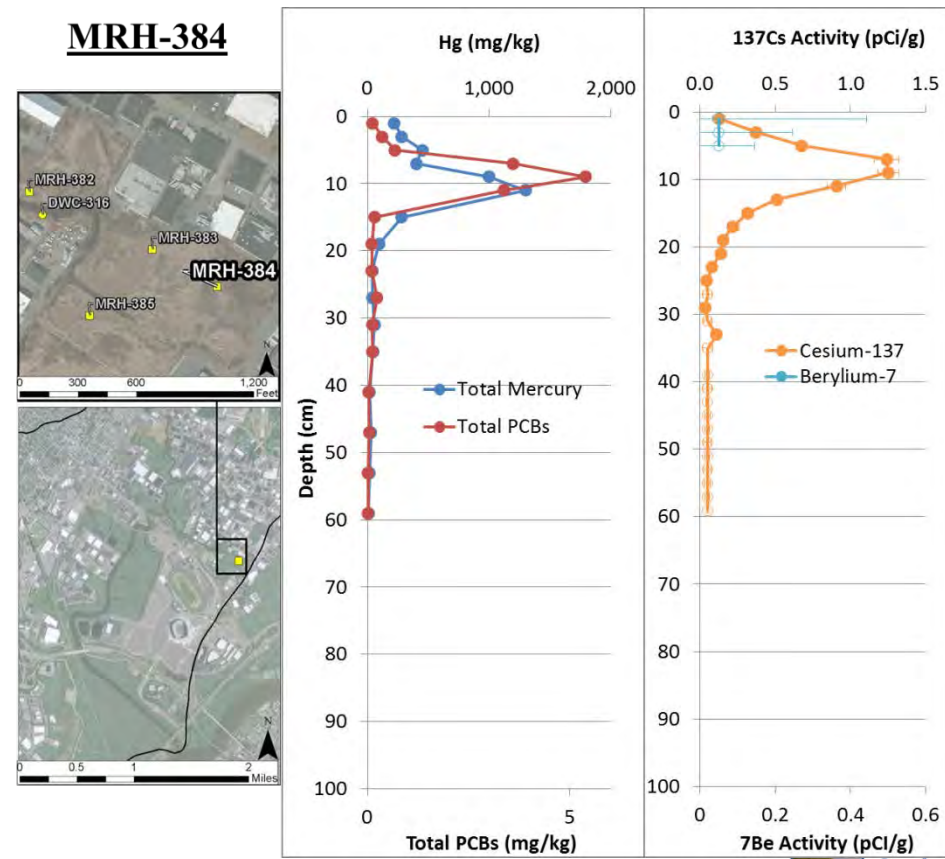
Typical Tidal Area Marsh Core (UBC)

MRH-396



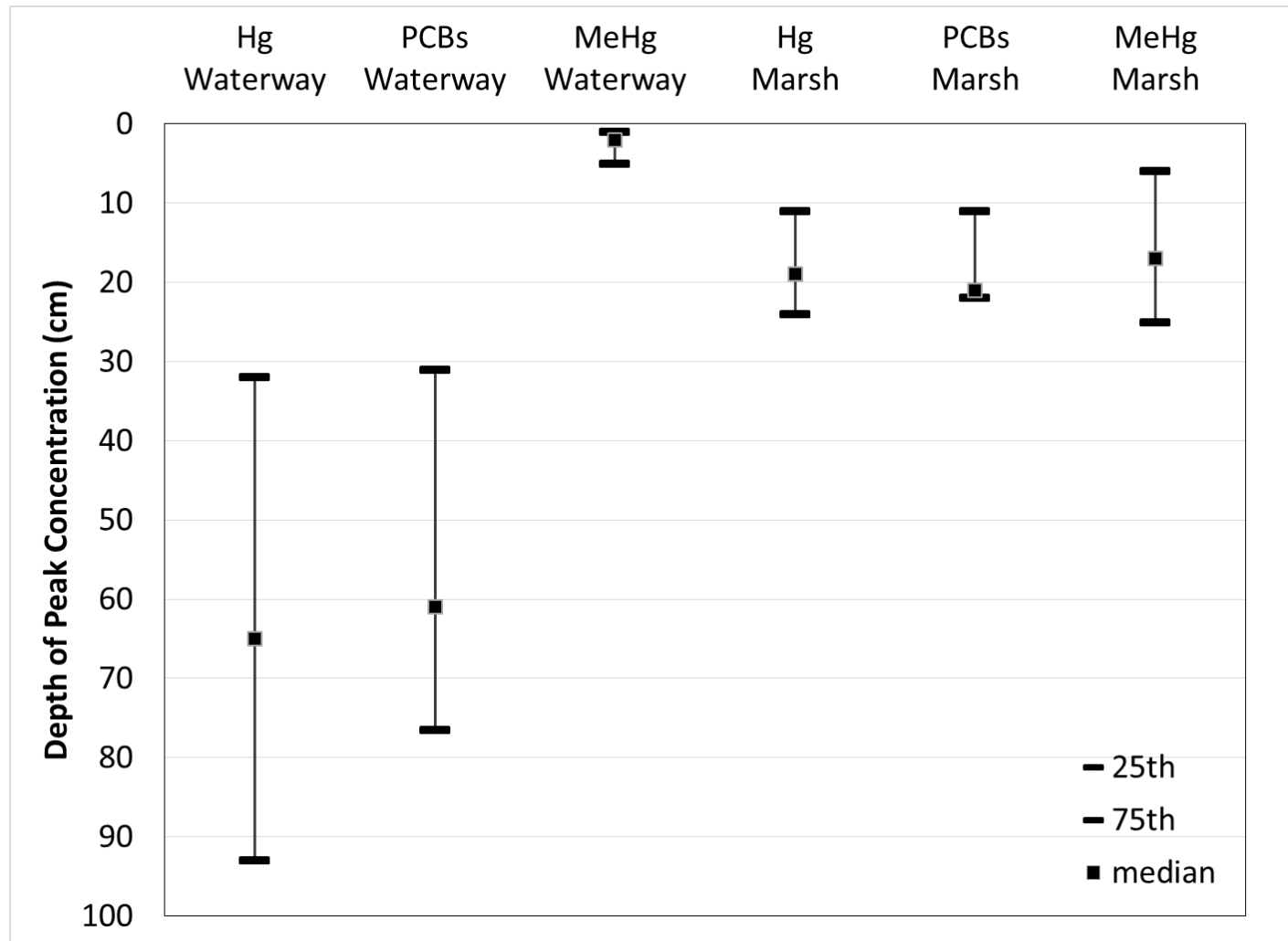
Typical UPIC Marsh Core

MRH-384



Depth of Peak Concentration in BCSA High Resolution Cores

53



Autochthonous Production in Marshes is a Substantial Source of Organic Matter

54



BCSA is Characterized by a Typical Estuarine Sediment Structure

55

- A common element of estuarine sediment beds is a thin (<0.5 cm) surface layer of unconsolidated, fine particulates termed the **Fluff Layer***

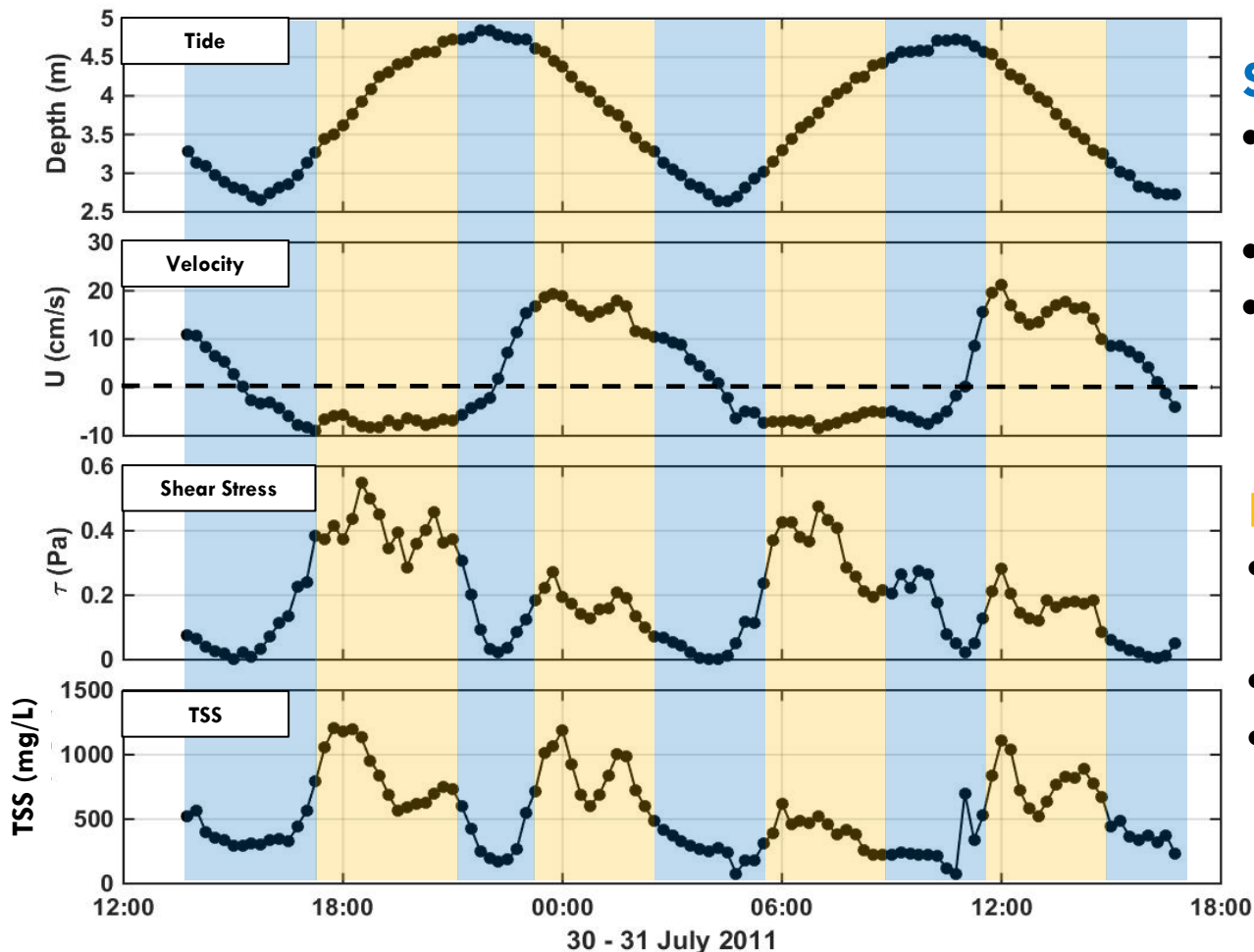
* (Sanford 1992; P.Y. Maa and Lee 2002; Small and Prahl 2004)



The Fluff Layer is Regularly Resuspended and Deposited with Tidal and Storm Flows

56

Nearbed Monitoring Study

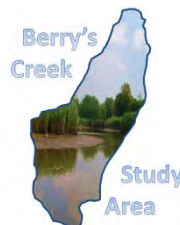


Slack tide

- low velocity and shear stress
- particulate deposition
- decreased TSS concentrations

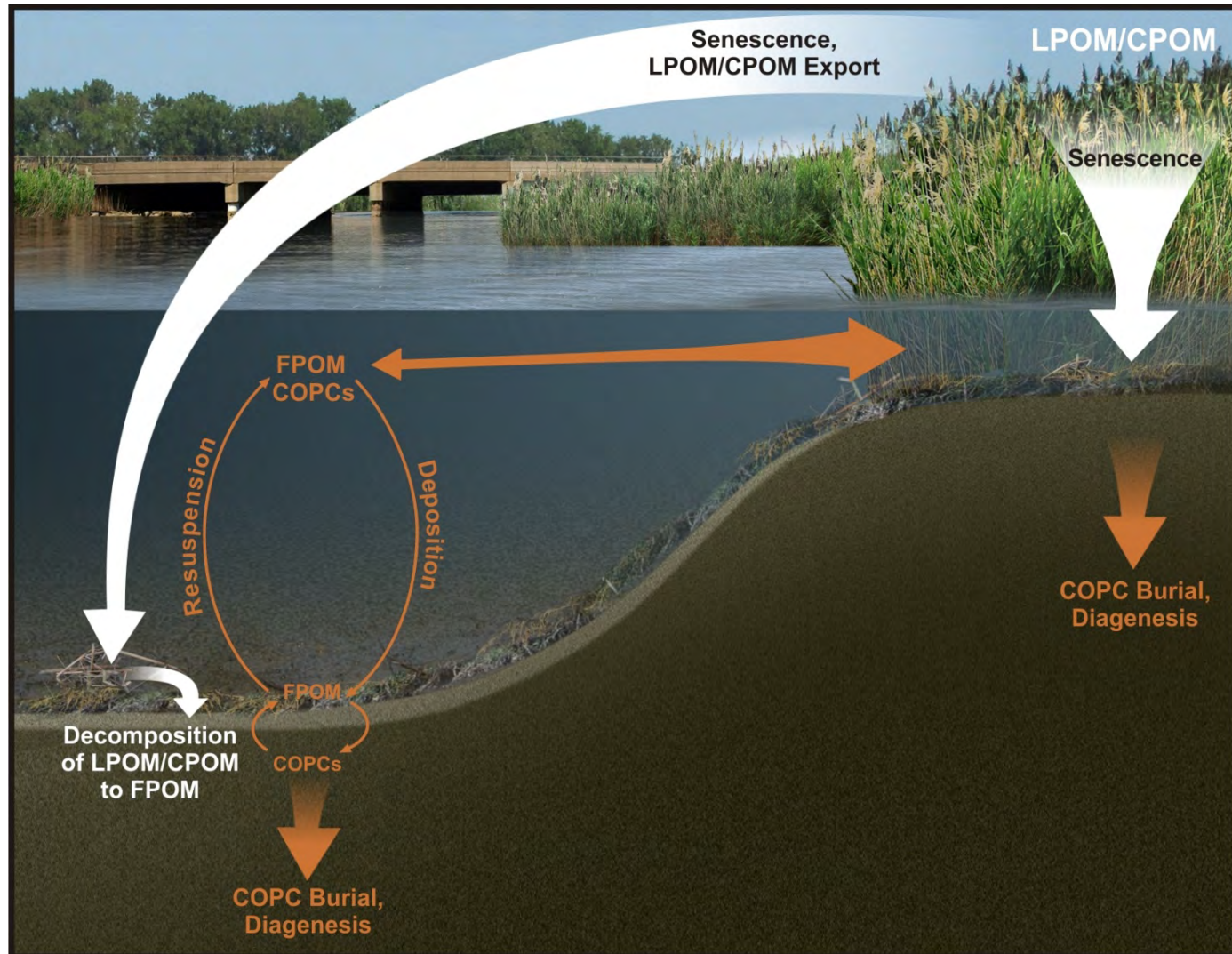
Peak flood and ebb tide

- higher velocity and shear stress
- particulate resuspension
- increased TSS concentrations



Influence of Particulate Interactions on Surface Water Quality

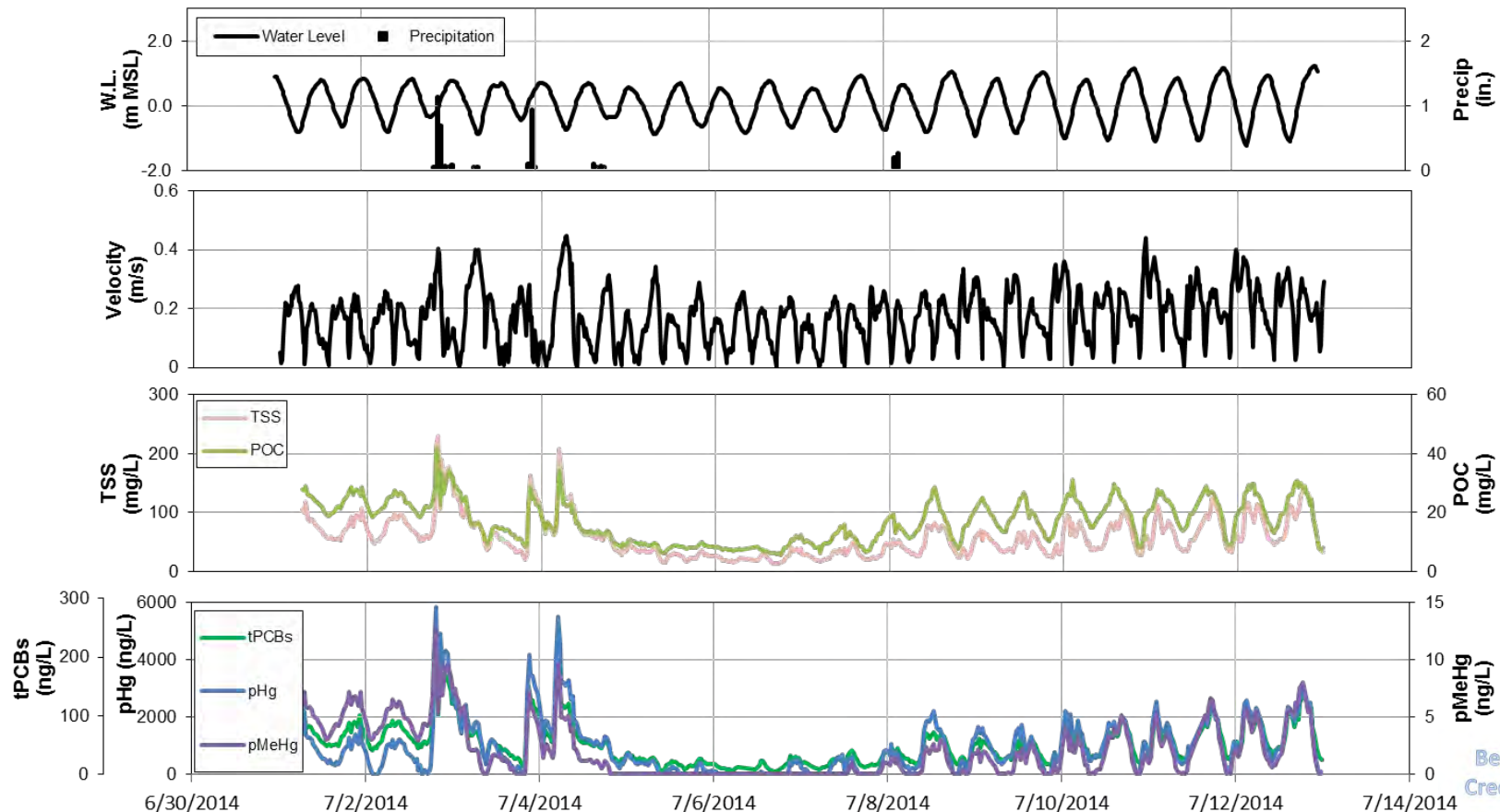
57



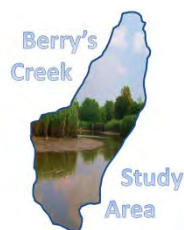
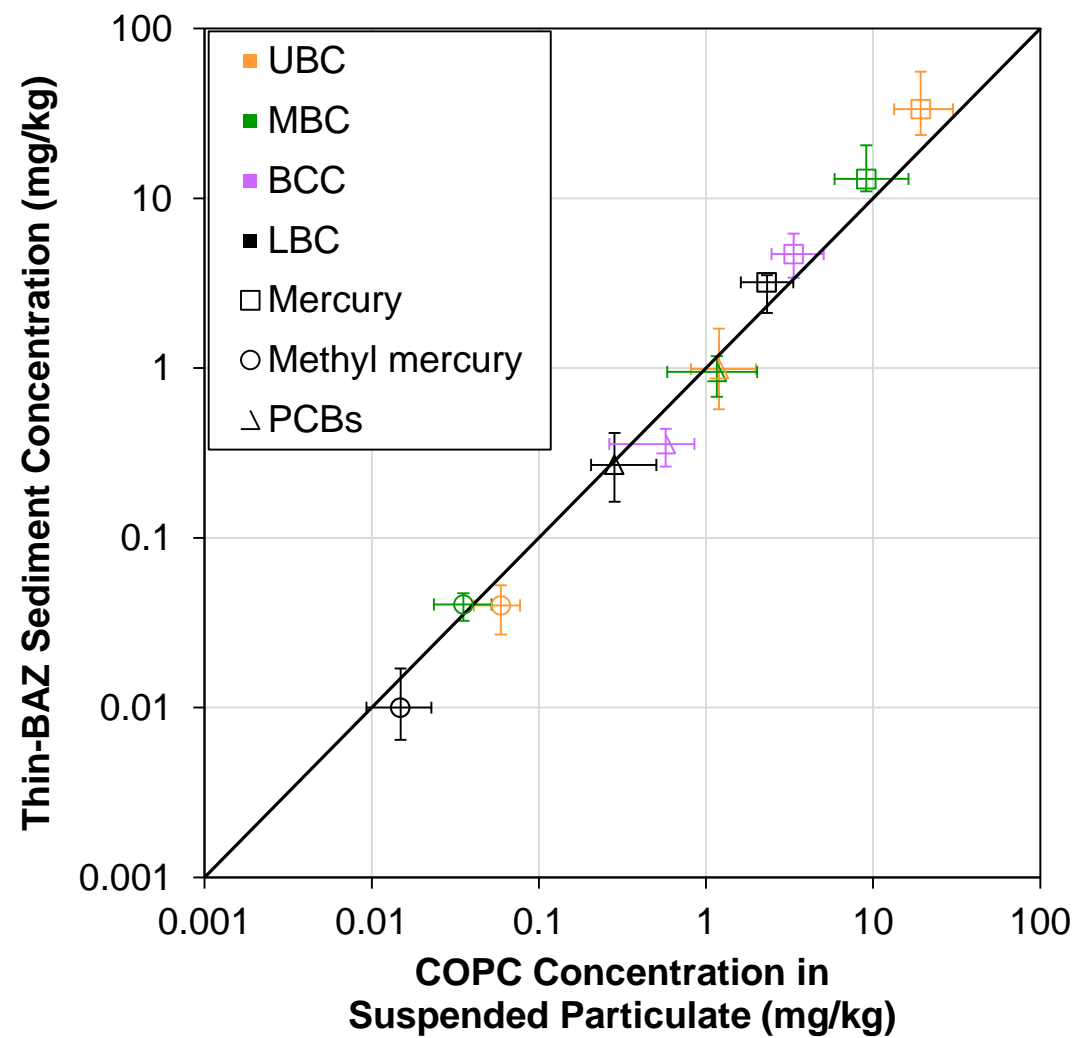
COPCs in Surface Water are Strongly Tied to Interaction of the Fluff Layer with the Waterway Sediment Bed

58

Optical Monitoring at Paterson Plank Road (Base of UBC)

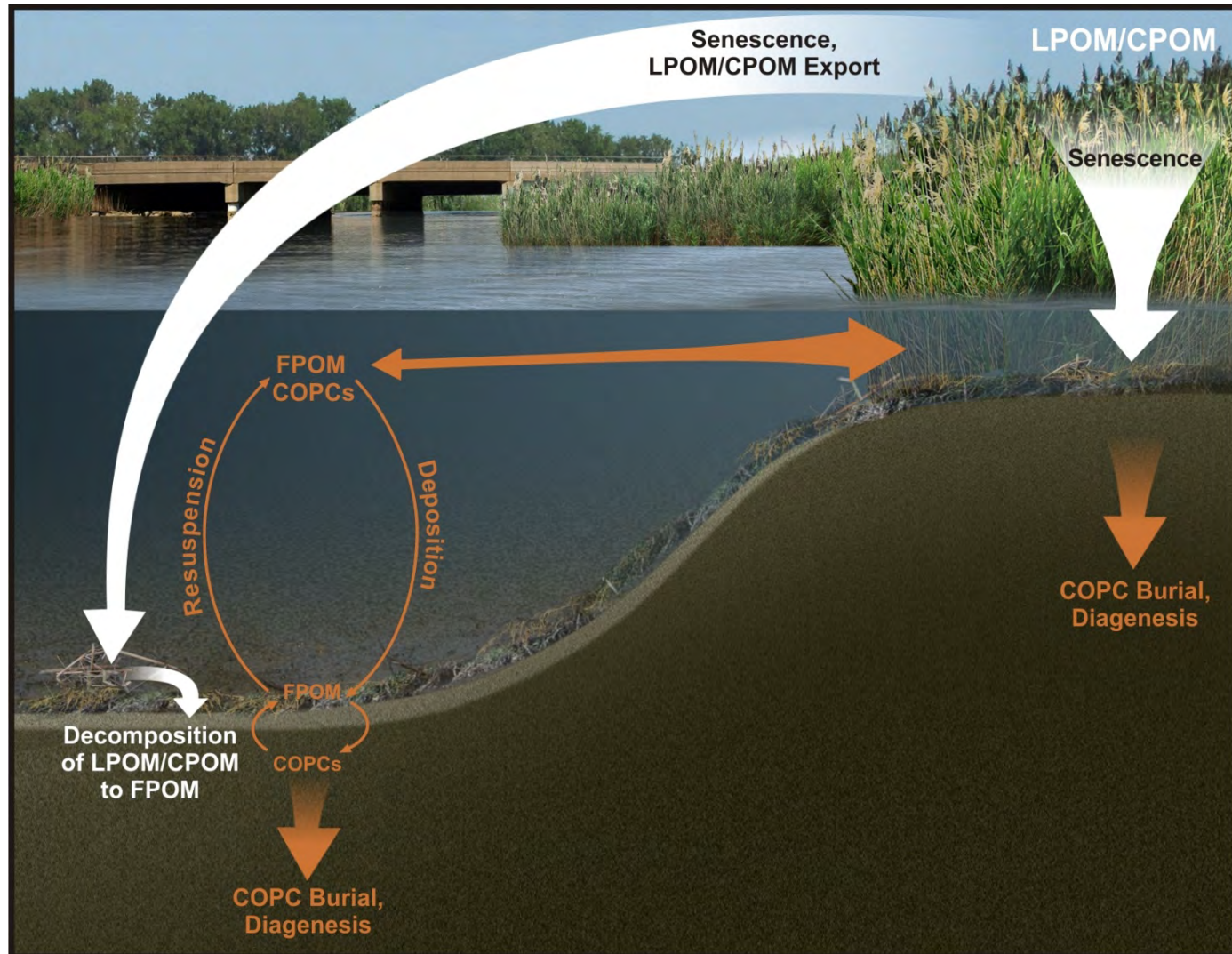


Surface Water COPC Concentrations at a Reach Scale are Consistent with COPCs in Surface Sediment



Marshes are Effective at Trapping Sediment Carried into the Marsh from the Waterways during Tidal Flooding

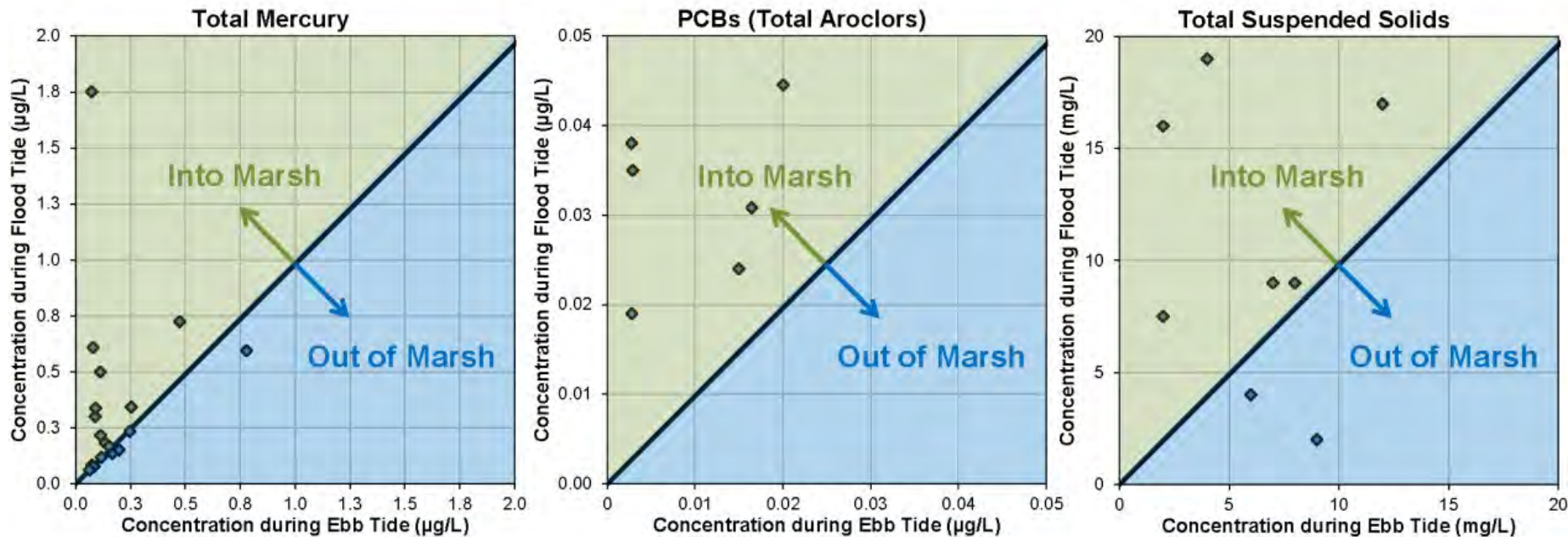
60



There is a Net Mass of TSS and Particulate COPCs Imported From the Waterways to the Marshes

61

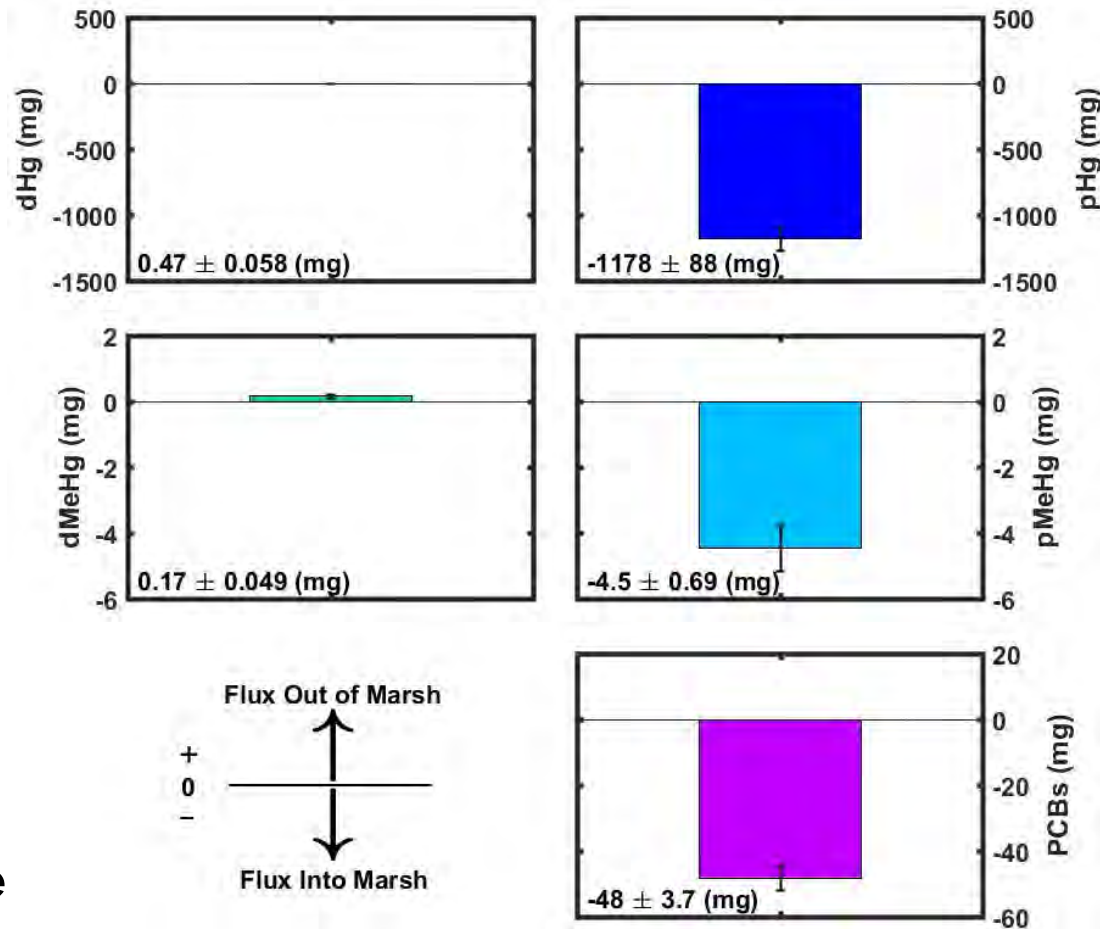
Conventional Sampling of Particulate COPC and TSS Exchange between the Marshes and Waterways



Net Exchange of MeHg is from the Waterways to the Marshes

62

- **2014 Optical Monitoring Study**
 - ▣ **Verifies that there particulate COPCs are imported into the marshes**
 - ▣ **Shows dissolved MeHg is exported from the marshes, but flux is much smaller than the flux of particulate MeHg imported into the marshes**



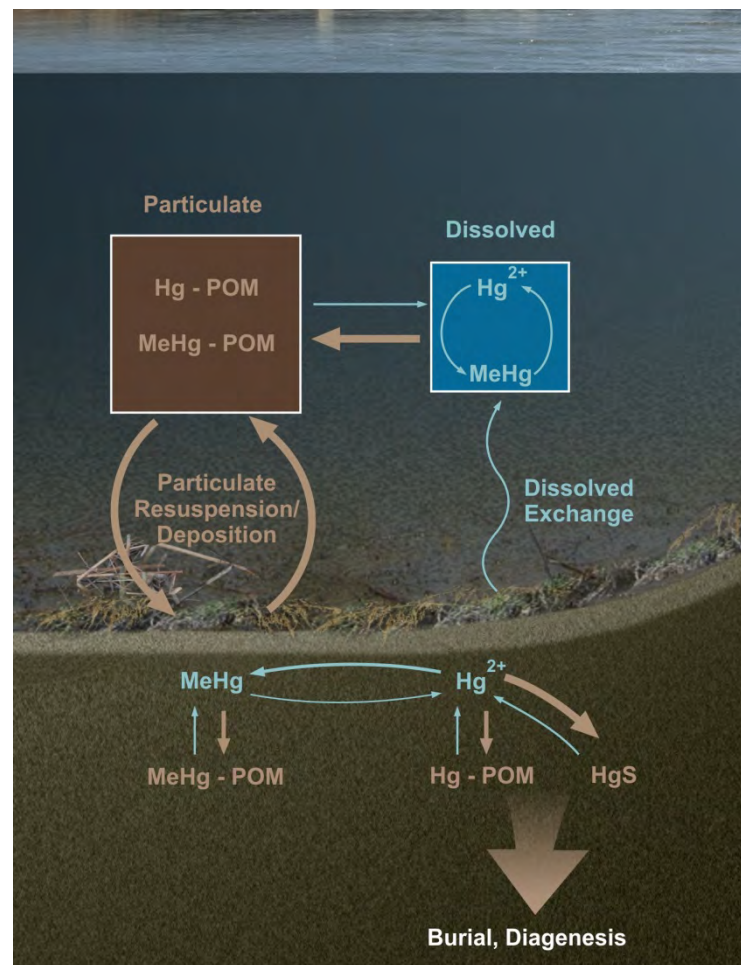
Key Finding 7

Natural conditions in the fringing marsh system sequester COPCs and reduce bioavailability

COPC Fate and Transport is Influenced by Chemical Partitioning

64

- COPCs are principally associated with the particulate phase
- Mercury speciation is strongly influenced by geochemistry
 - ▣ Methylation and demethylation are redox dependent
 - ▣ Hg availability for methylation is limited by sulfide complexation
- PCBs and Hg bind to organic matter



Marshes and Other Sources Have Resulted in High Concentrations of Organic Matter in BCSA

65

- ❑ **COPCs strongly binds with POC, which limits bioavailability**
- ❑ **Organic matter is a substrate for microbial metabolic processes and influences redox conditions**

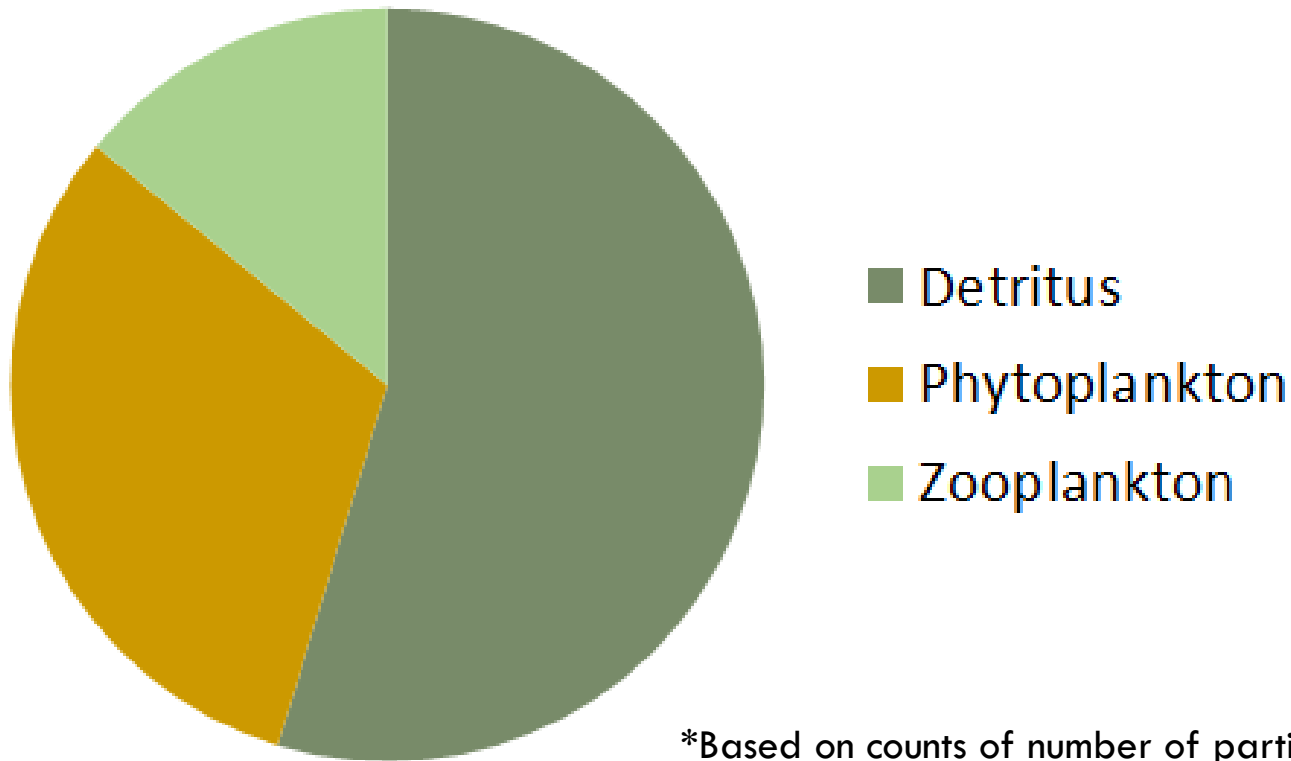
Average Organic Matter Concentrations in BCSA Sediment and Suspended Particulate

Media	Average Percent Organic Matter
Waterway sediment	6
Marsh sediment	19
Surface water particulate	26

***Phragmites* is an Important Food Source for the Detritus-Based Food Web – Decreases Biouptake**

66

- **Suspended particulates in the water column are dominated by organic detritus**

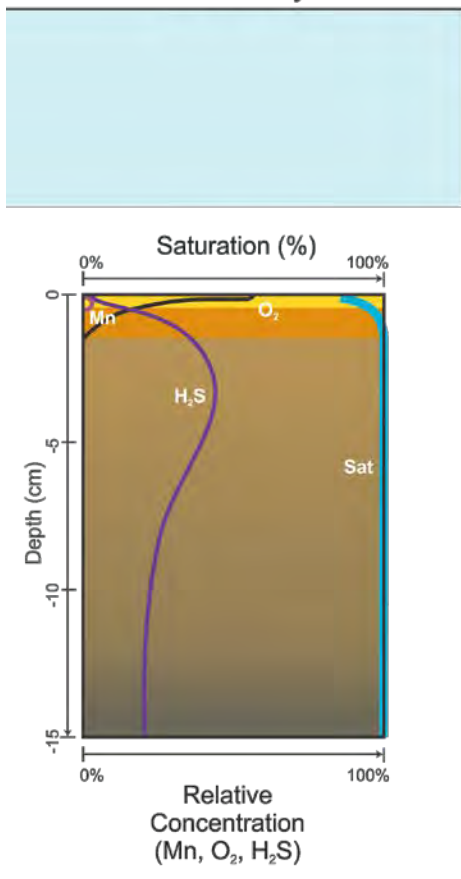


*Based on counts of number of particles

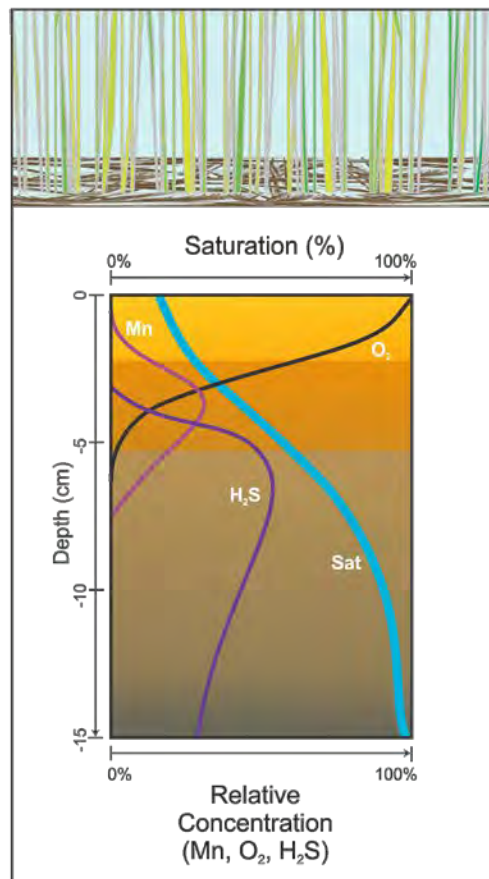
Redox Conditions Vary with Physical Setting and Hydrologic Conditions

67

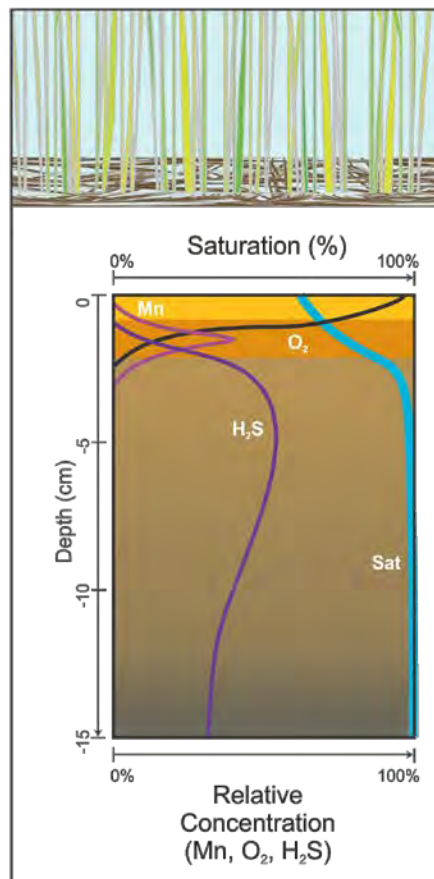
Waterway



Marsh Nearbank



Marsh Interior

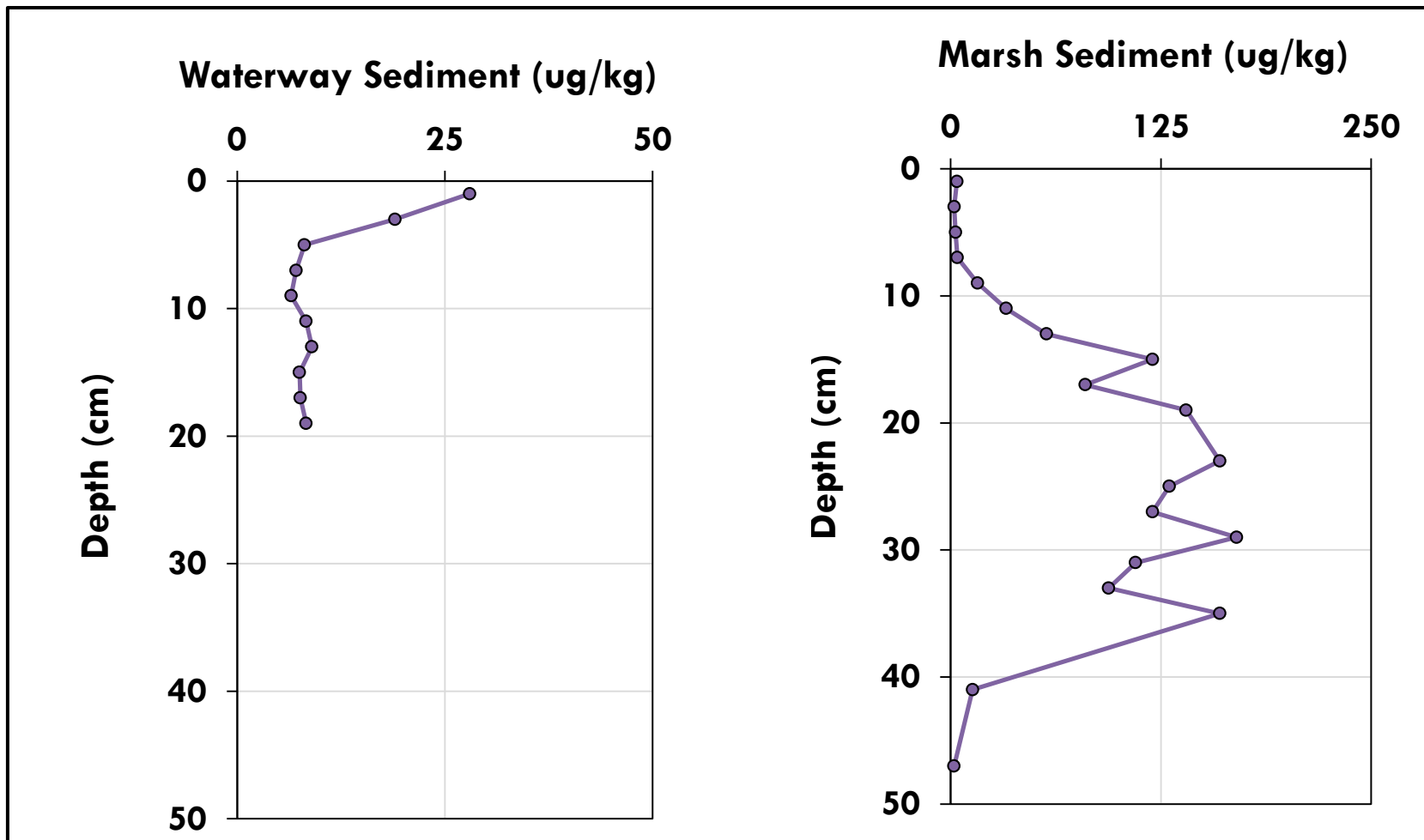


Legend:

- Saturation
- Sulfide
- Manganese
- Dissolved Oxygen
- Oxidic Zone
- Suboxic Zone
- Anoxic Zone

Example of Vertical Distribution of MeHg in Sediment

68



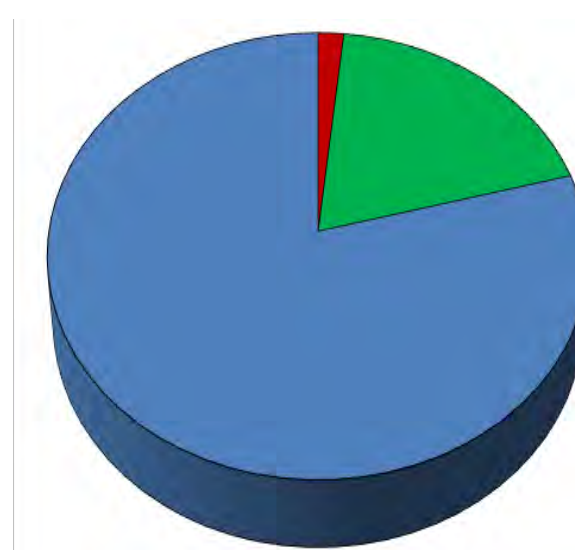
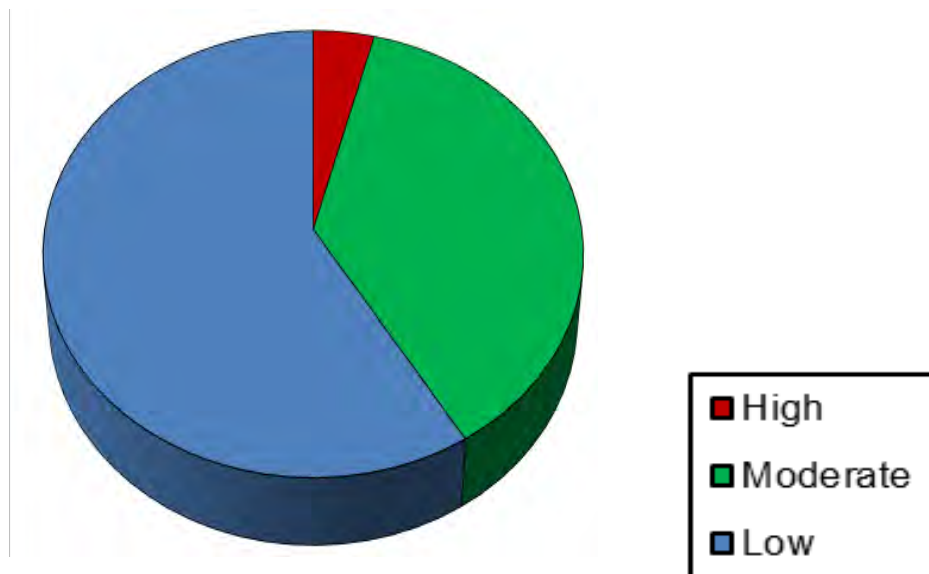
Bulk of Inorganic Hg is Bound in Sulfide/ Sulfhydryl Complexes that are Minimally Available

69

Average Distribution of Low, Moderate, and High Bioavailability Fractions Based on Selective Sequential Extraction Testing

Marsh Sediment

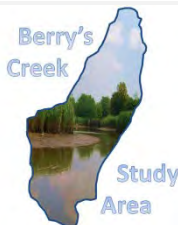
Waterway Sediment



Includes all data collected from BCSA (all reaches, surface and subsurface depth intervals)

Key Finding 8

COPC biouptake is linked to surface sediment in the waterways and tributaries



COPCs in Fish Tissue

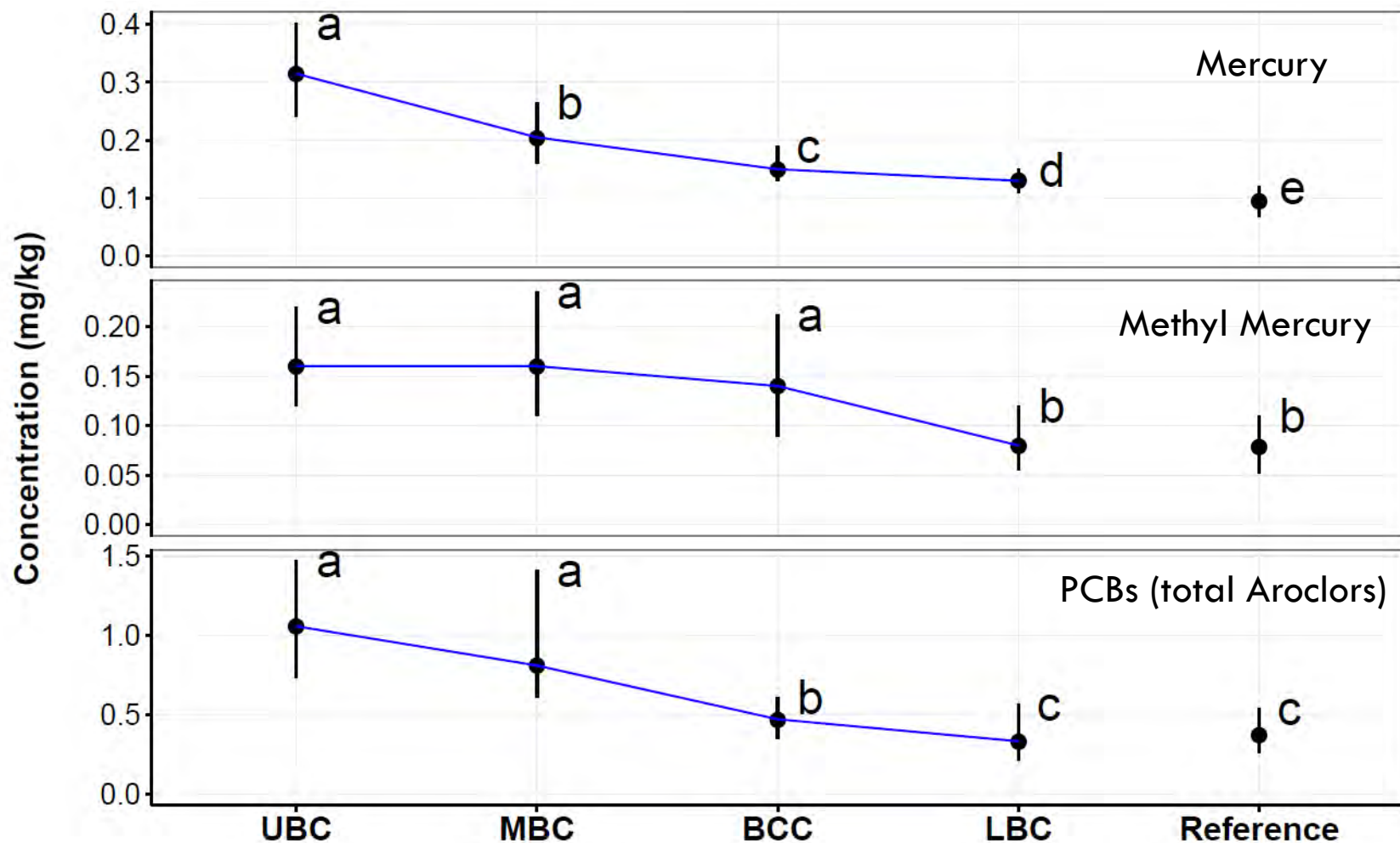
71

- **Consistent pattern of higher concentrations in the upper reaches, paralleling that in sediment**
- **Concentrations in the lower reaches approaching that in reference sites**



COPCs in Mummichog

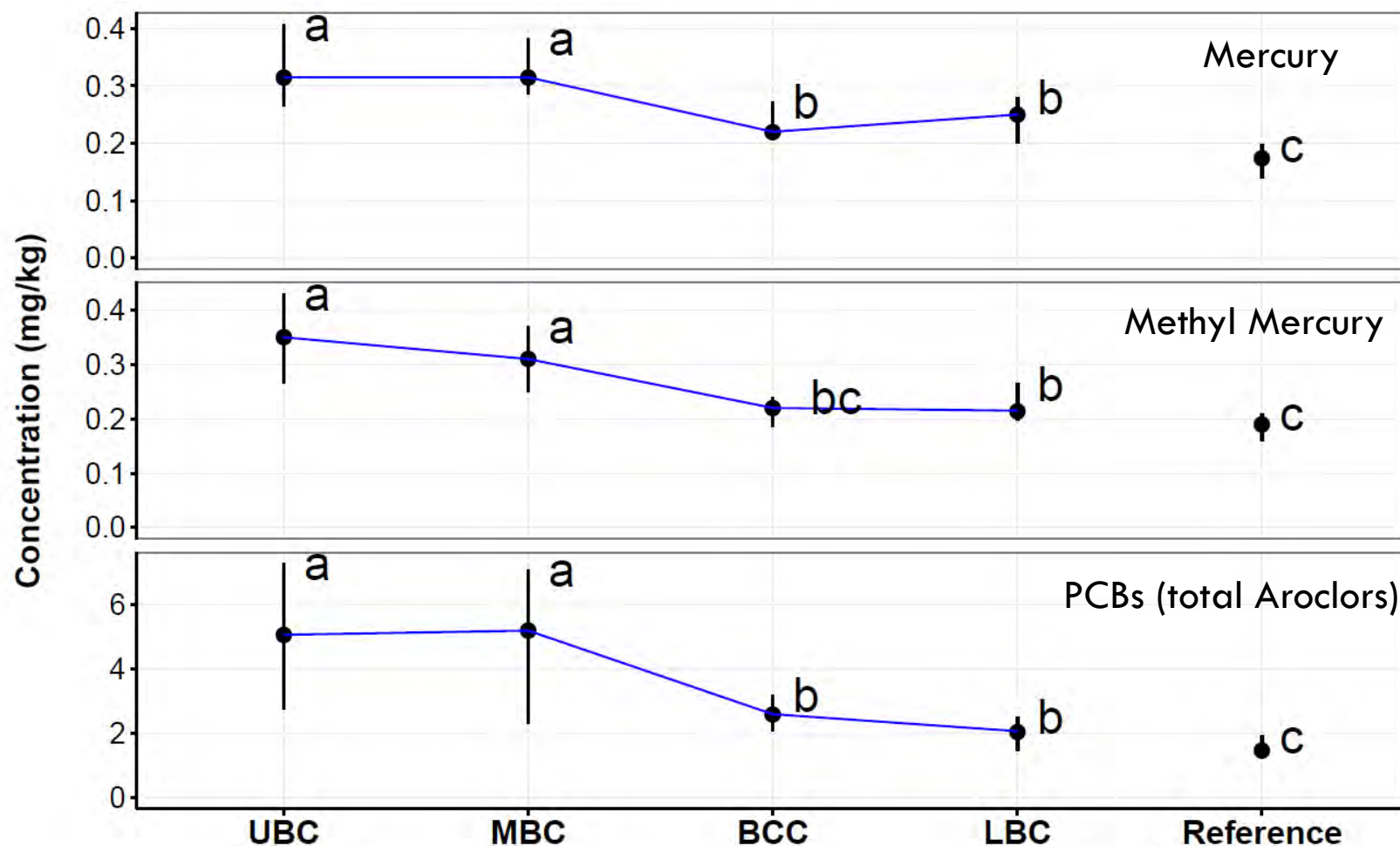
72



- Dots represent median & bars represent inner quartile range.
- Pairwise non-parametric comparison of medians (Wilcox rank sum) with Bonferroni p-value adjustment at 0.05.

COPCs in White Perch

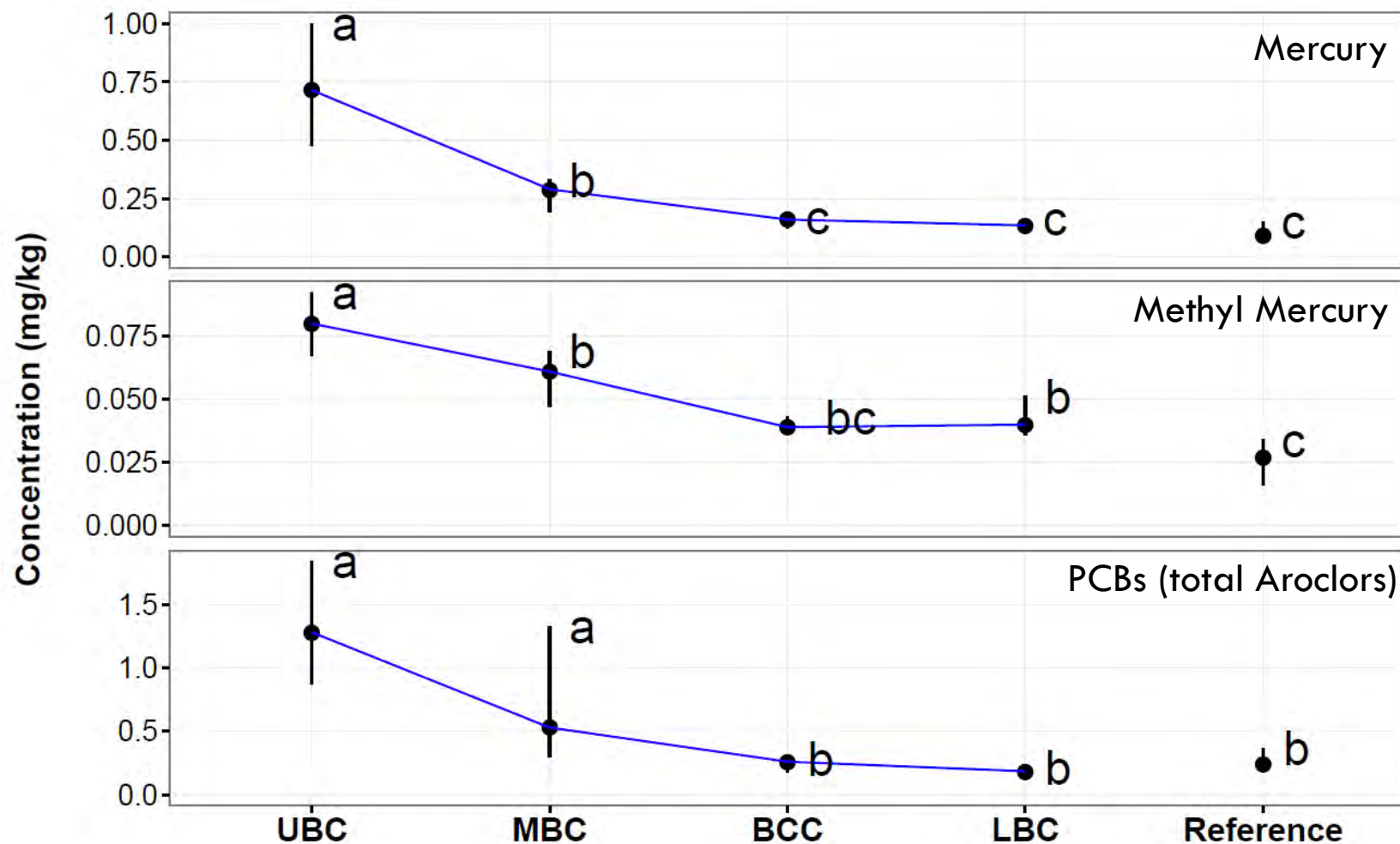
73



- Dots represent median & bars represent inner quartile range.
- Pairwise non-parametric comparison of medians (Wilcox rank sum) with Bonferroni p-value adjustment at 0.05.

COPCs in Fiddler Crabs

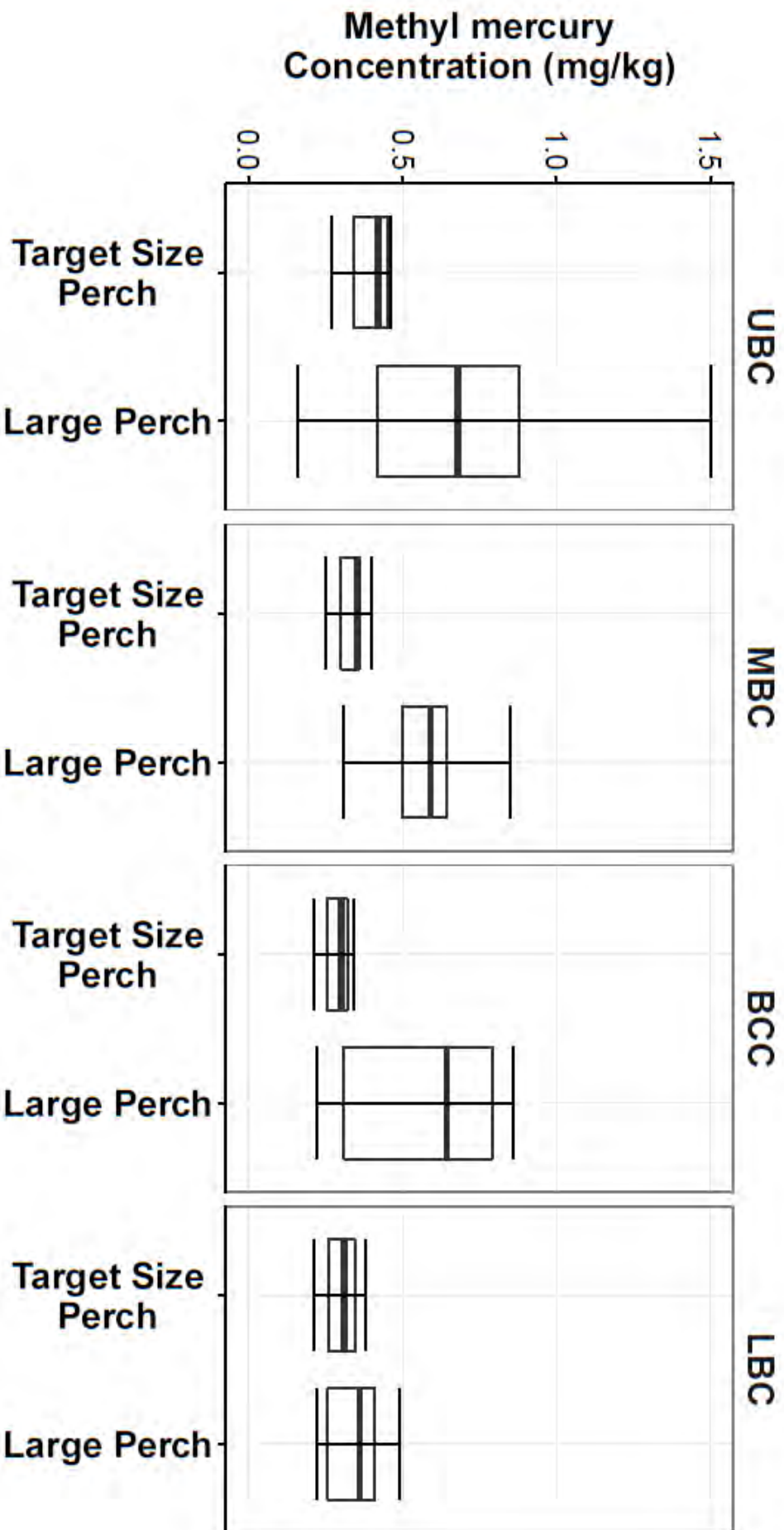
74



- Dots represent median & bars represent inner quartile range.
- Pairwise non-parametric comparison of medians (Wilcox rank sum) with Bonferroni p-value adjustment at 0.05.

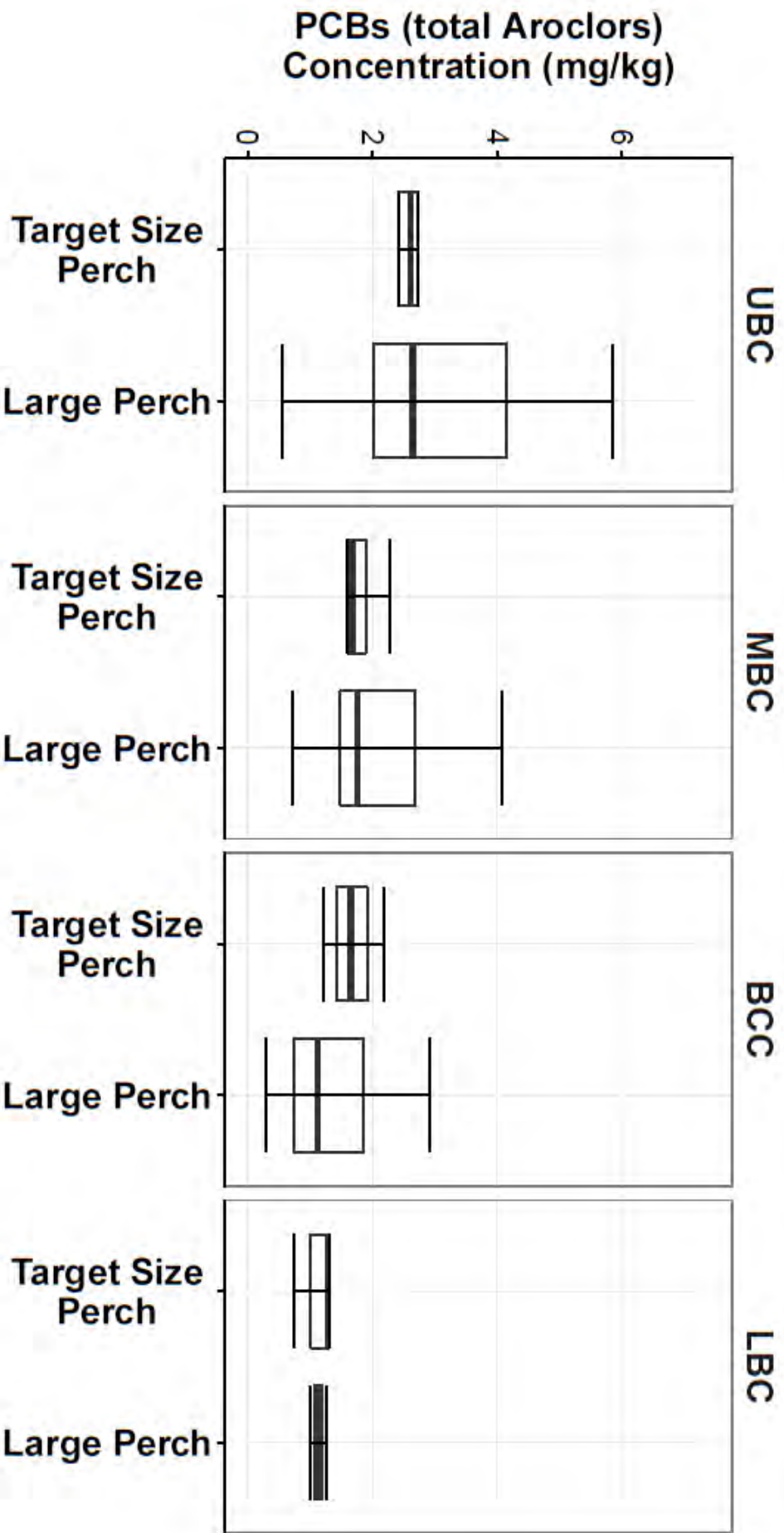
MeHg Higher in Larger Perch

75



PCBs Similar Levels in Larger Perch

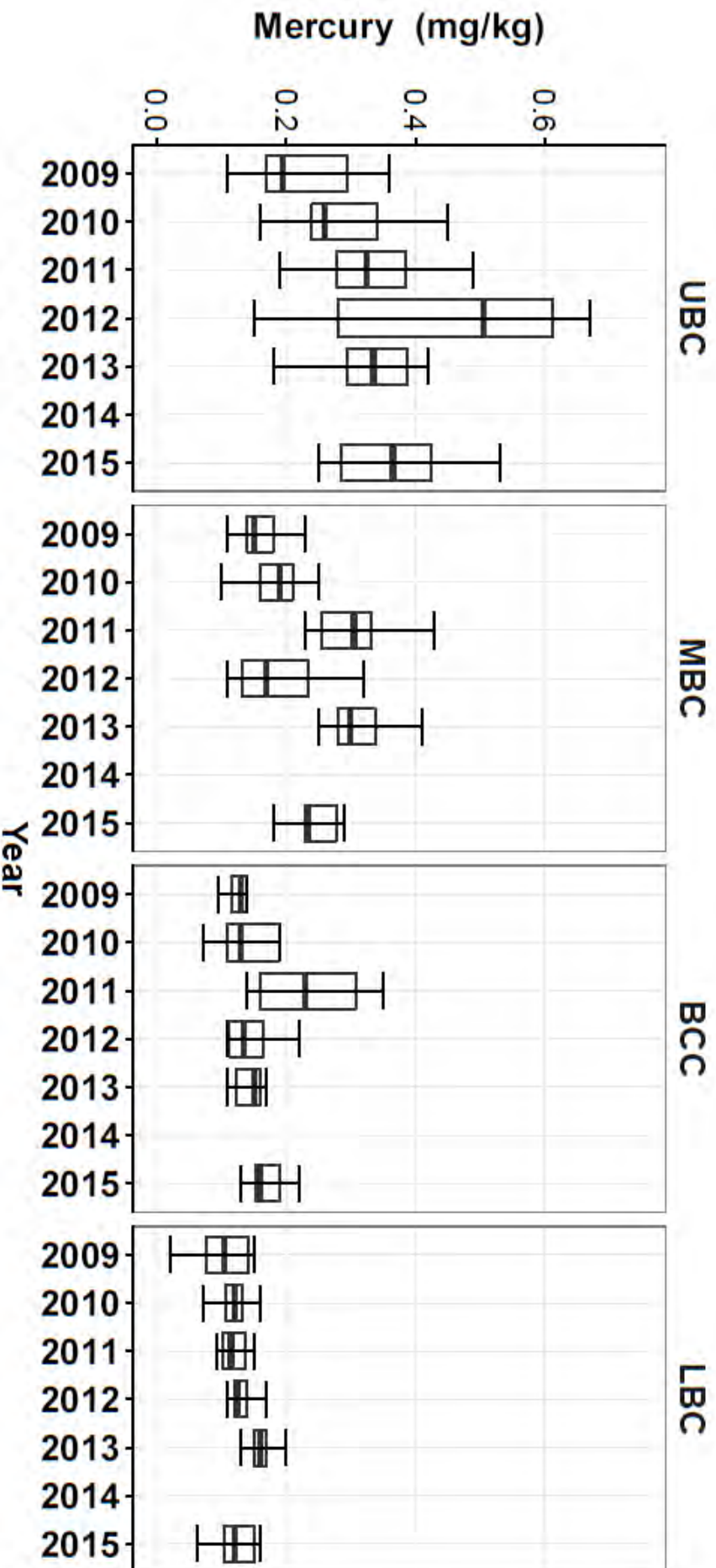
76



Variability in COPCs

77

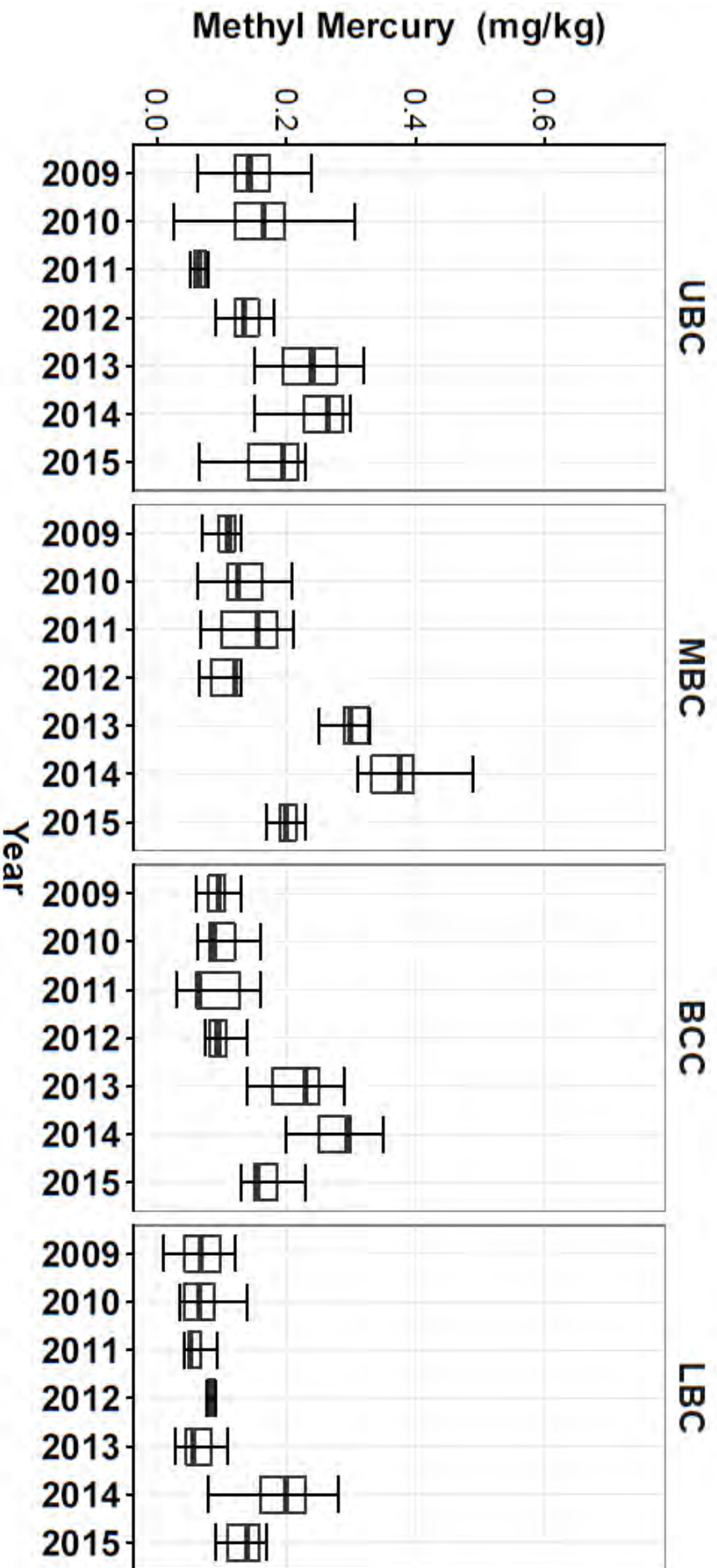
Mummichog - Mercury



Variability in COPCs

78

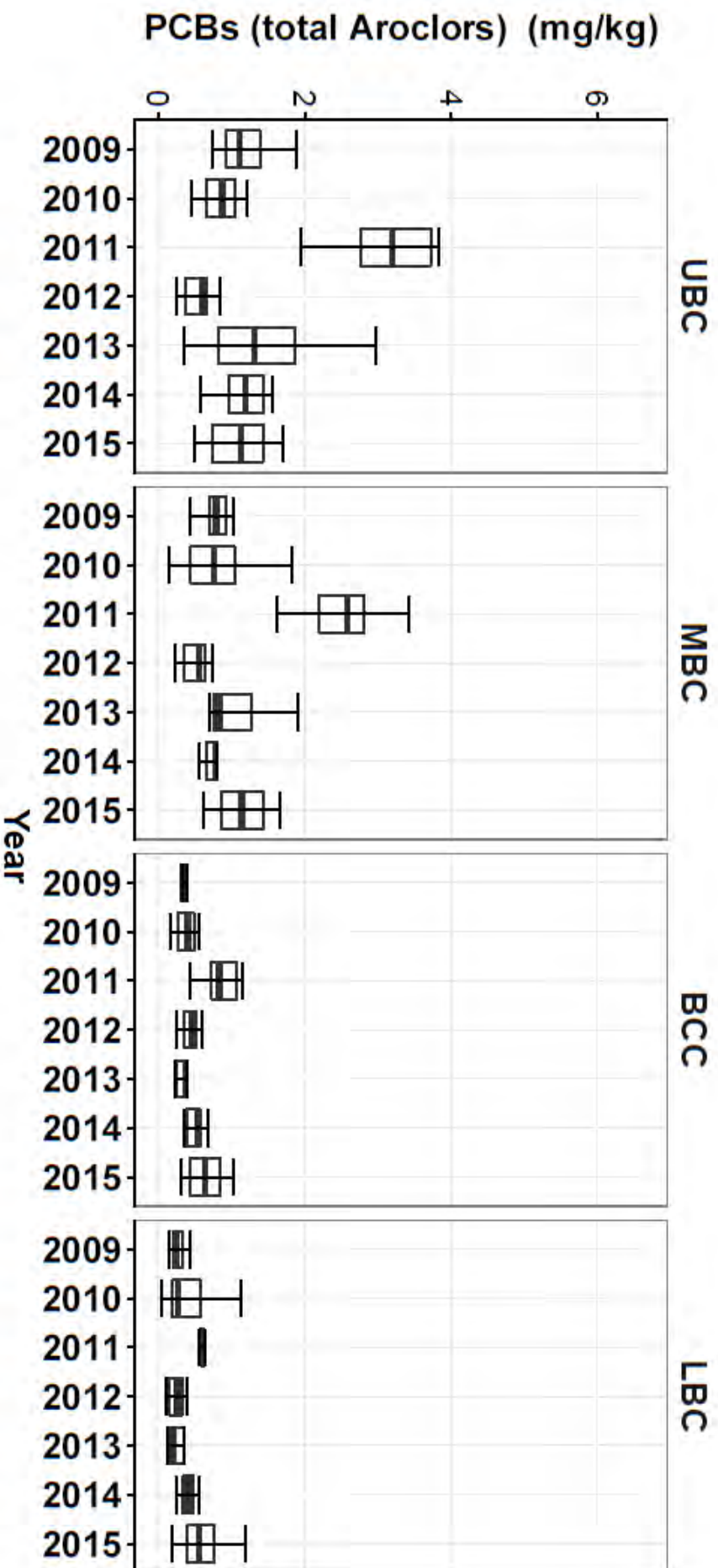
Mummichog – Methyl Mercury



Variability in COPCs

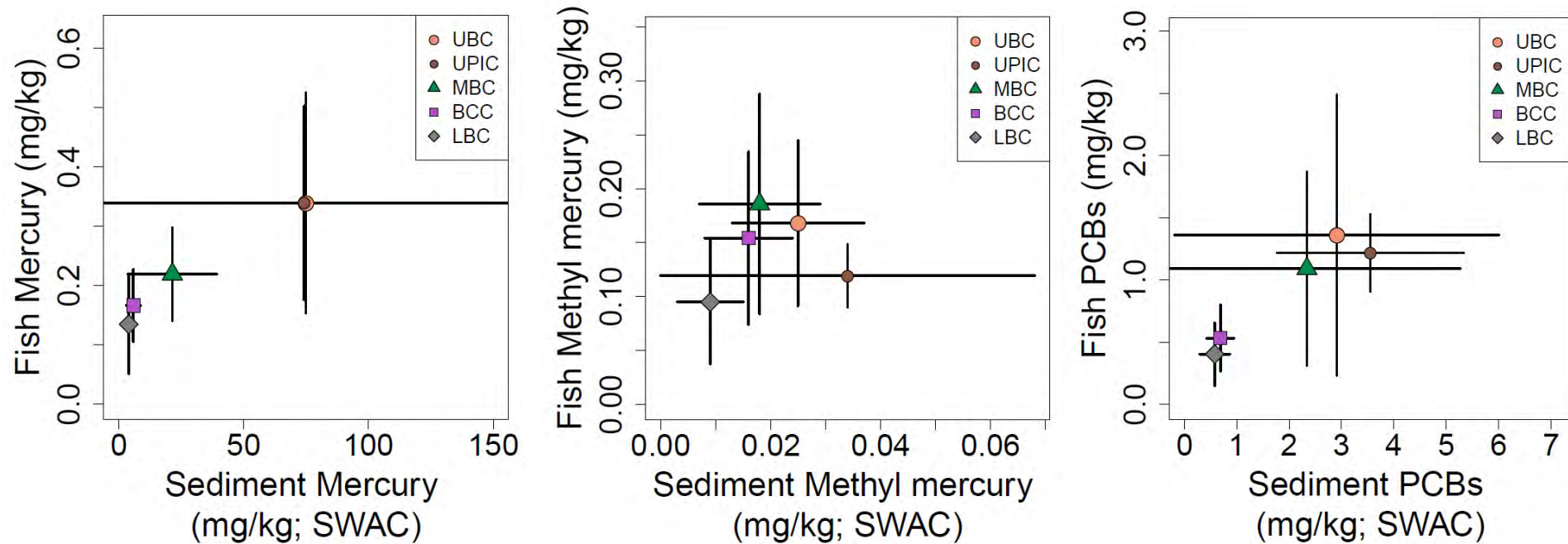
79

Mummichog - PCBs



Fish Tissue Concentrations Track Sediment, Variability Limits Precision of Predictions

80



Mummichog data;
mean & standard deviation

Marsh Biota – Less Direct Connection to Sediment

81

- **Marsh sediment at depth not bioaccessible**
- **Plant uptake of COPCs occurring, but limited**
- **Marsh surface primary exposure point (detrital layer)**
- **COPC concentrations in marsh detrital layer**
 - ▣ **Lower than in sediment**
 - ▣ **Likely a function of waterway particulate loading**



***Phragmites* Poses Physical Barrier to Marsh Sediments for Most Receptors**

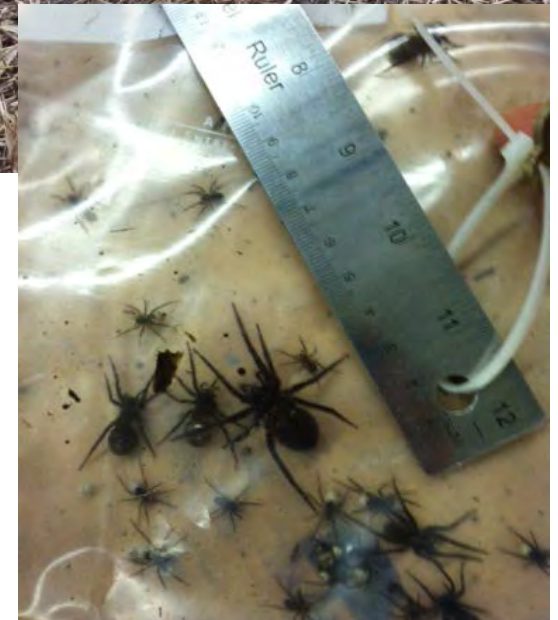
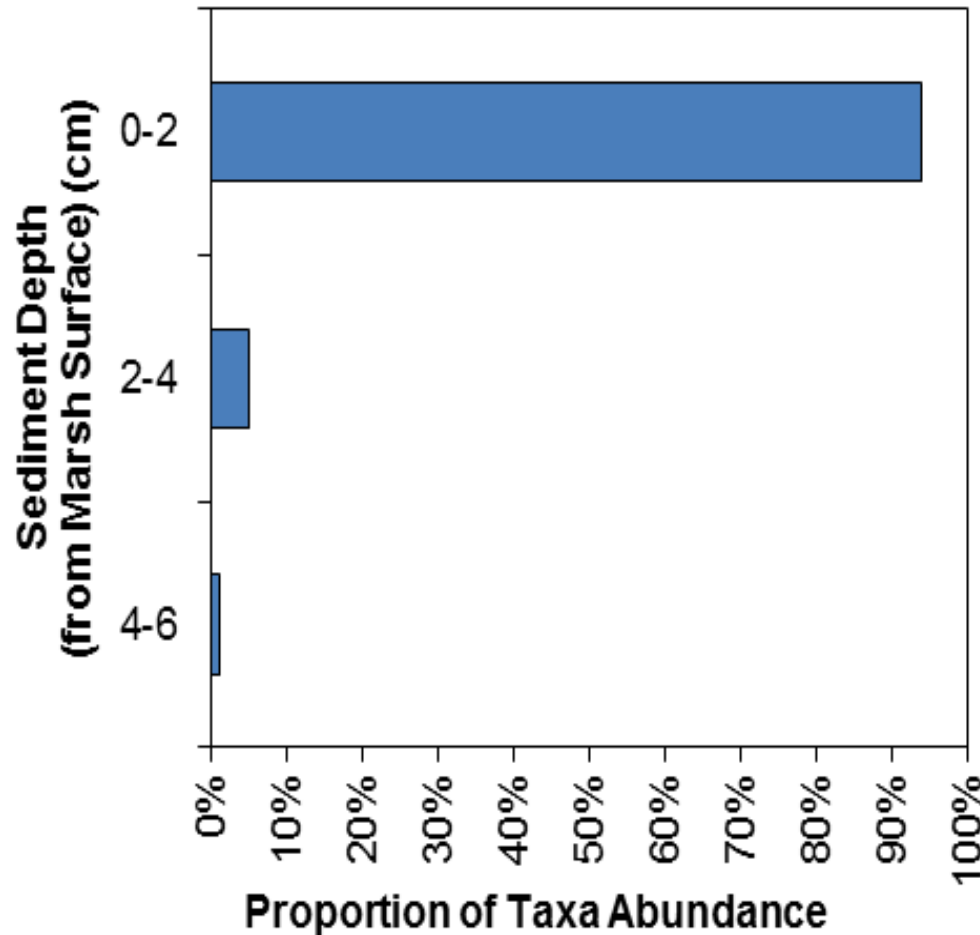
82



April 13, 2016 Presentation to EPA of RI Findings

Biological Activity on Marsh Surface, Primarily in Detritus & Vegetation

83

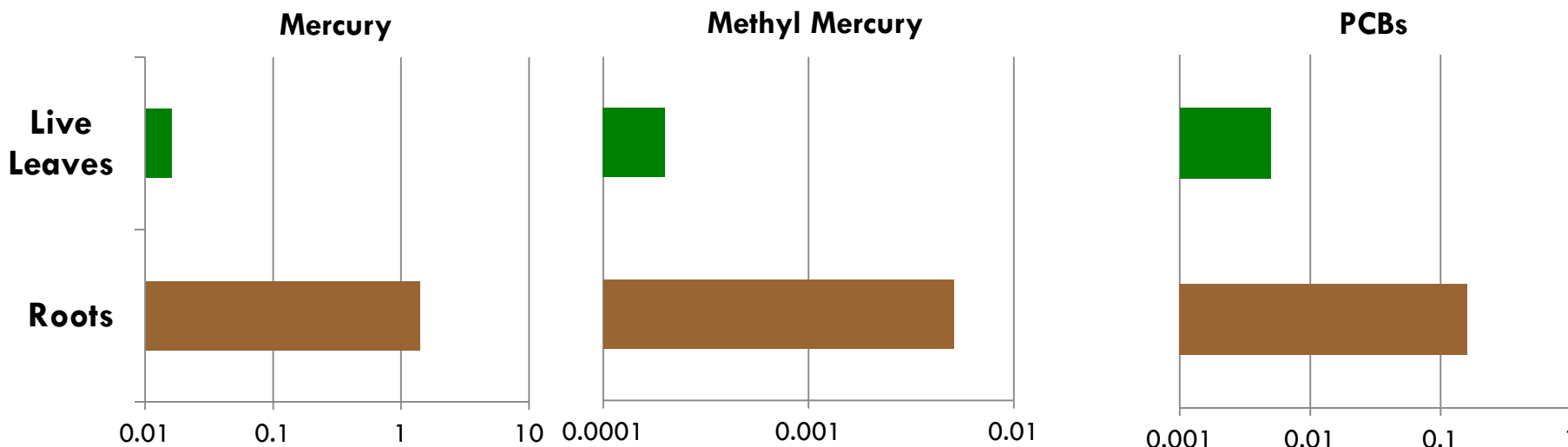


Phragmites Roots Accumulate COPCs, but little Above-ground Transport

84

Median COPC Concentrations in *Phragmites* Roots and Leaves in BCSA Marshes

COPC	Concentration (mg/kg)		Ratio Leaves:Root
	Roots	Leaves (Live)	
Mercury	1.4	0.016	0.01
Methyl Mercury	0.0051	0.0002	0.04
PCBs	0.16	0.0055	0.03

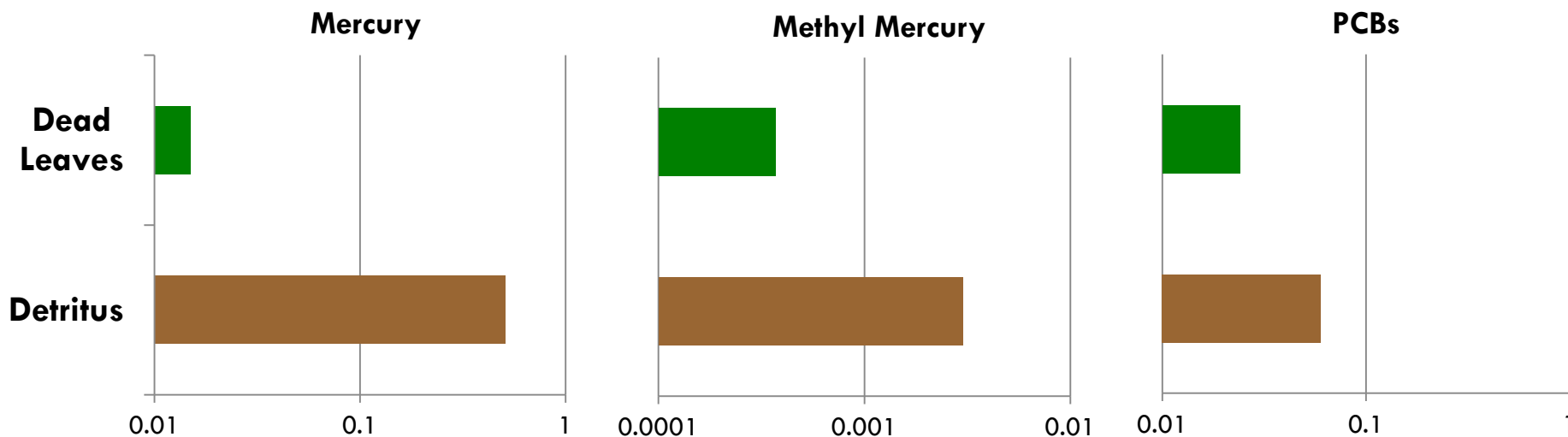


COPCs on Marsh Detritus > than in Leaves

85

Median COPC Concentrations in *Phragmites* Leaves and Detritus in BCSA Marshes

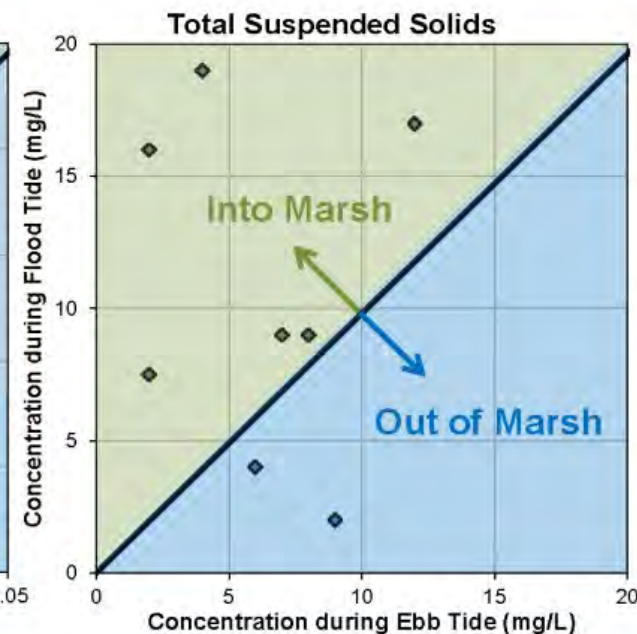
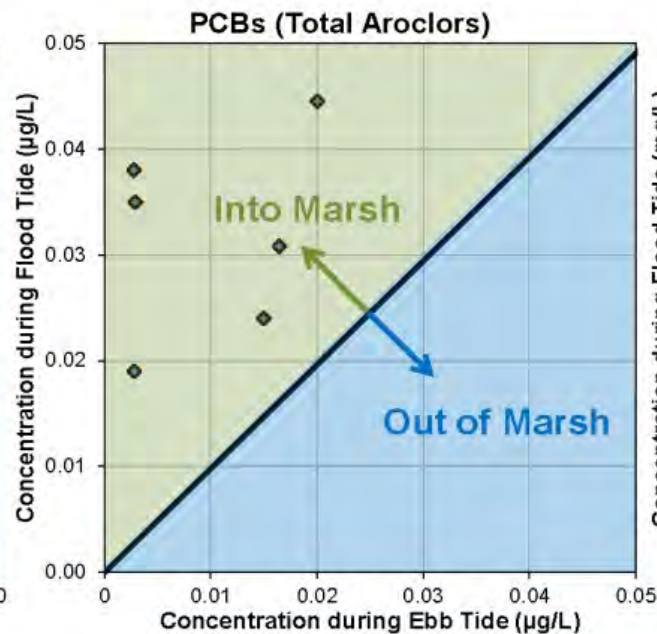
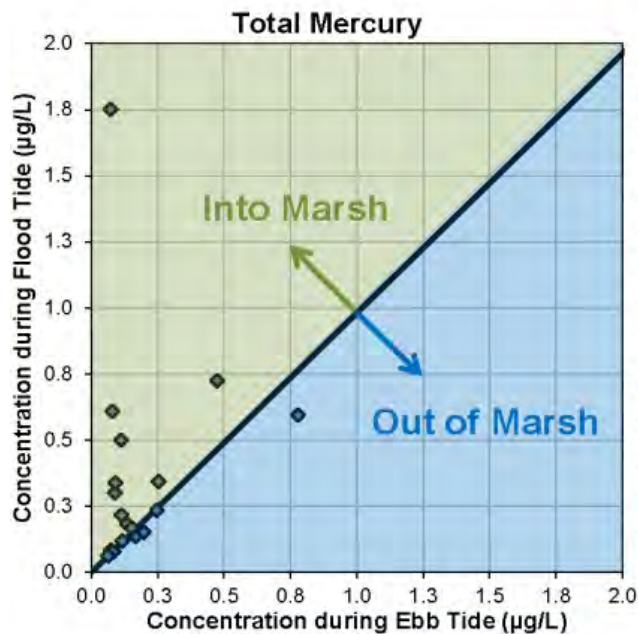
COPC	Concentration (mg/kg)		
	Leaves (Live)	Leaves(dead)	Detritus
Mercury	0.016	0.015	0.51
Methyl Mercury	0.0002	0.00037	0.0030
PCBs	0.0055	0.024	0.060



COPCs on Marsh Detritus > Leaves Likely a Function of Waterway Particulate

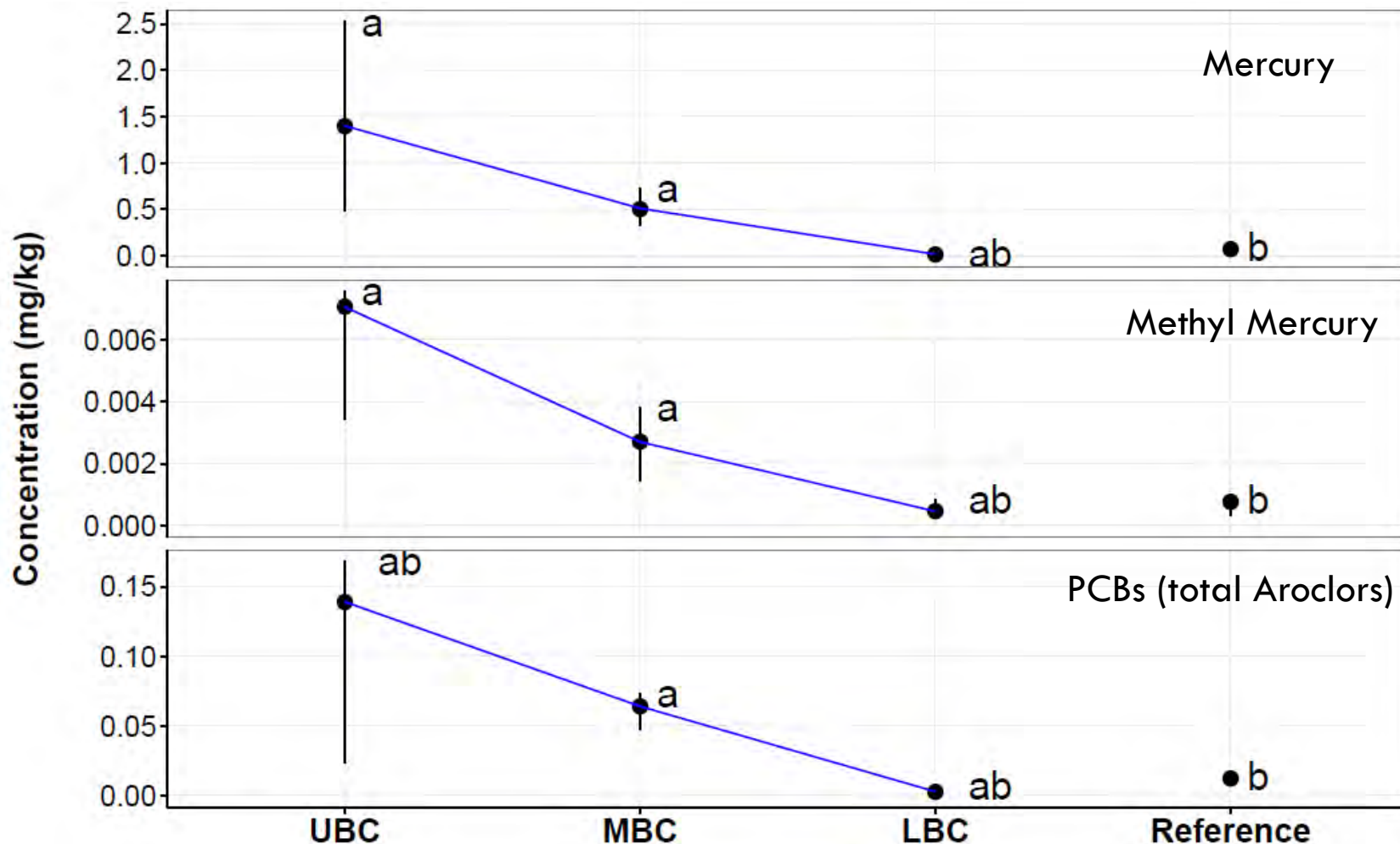
86

- Consistent with Site data
- Consistent with literature



COPCs on Marsh Detritus – Similar Pattern, Lower Concentration than Waterway Sediment

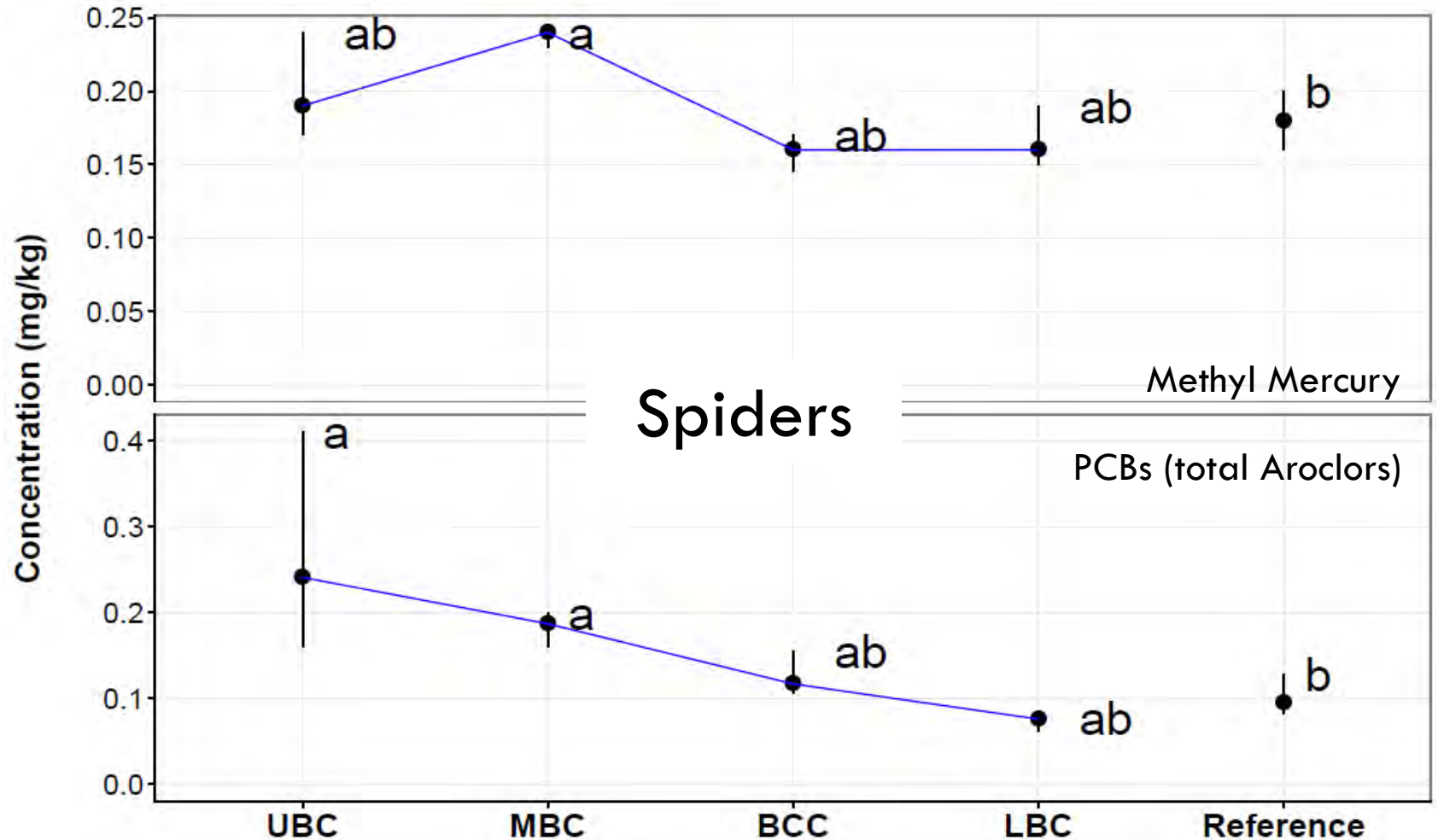
87



- Dots represent median & bars represent inner quartile range.
- Pairwise non-parametric comparison of medians (Wilcox rank sum) with Bonferroni p-value adjustment at 0.05.

Marsh Biota Can Accumulate COPCs from Marsh Surface

88



- Dots represent median & bars represent inner quartile range.
- Pairwise non-parametric comparison of medians (Wilcoxon rank sum) with Bonferroni p-value adjustment at 0.05.

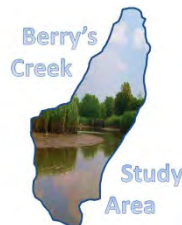
Key Findings 9 and 10

- **Ecological Risk Findings**
- **Human Health Risk Findings**
- **Presentation in late July or early August**

Summary of Key Findings

90

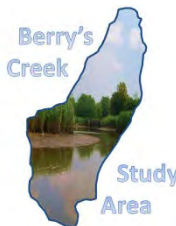
1. **The BCSA includes a stable and net depositional tidal area**
2. **COPC concentrations are substantially higher in the northern end of the study area**
3. **The urban setting has altered the physical, chemical, and biological character of BCSA, which are distinctly different from non-urban areas**
4. **Most COPC concentrations are lower at the sediment surface and are substantially higher at depth**



Summary of Key Findings

91

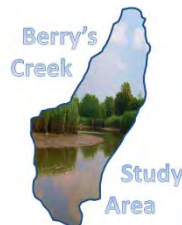
5. **Natural recovery is occurring in the waterways, though variable in magnitude due to occasional episodic re-working and resuspension of near surface sediment in localized areas**
6. **Marsh natural recovery is substantial and consistent, and is linked to sediment and COPC inputs from waterways**
7. **Natural conditions in the fringing marsh system sequester COPCs and reduce bioavailability**



Summary of Key Findings

92

8. **COPC biouptake is linked surface sediment in the waterways and tributaries**
9. **BCC and LBC COPC concentrations are attenuating consistent with regional conditions**



A photograph of a body of water, possibly a pond or a slow-moving stream. The water is dark and reflects the sky. In the foreground, there's a muddy, greyish-brown bank. Behind the bank, there's a dense thicket of tall, green reeds or grasses. In the background, a light-colored, possibly white, building is visible, partially obscured by more trees and foliage. The sky is overcast and grey.

QUESTIONS?